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ADMINISTRATIVE INFORMATION

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 Supplemental information pertaining to this report is available at http://environ.spawar.navy.mil/Projects/ENVVEST/FC_Model_Report/.

SB

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EXECUTIVE SUMMARY

INTRODUCTION

In this report we document the development, calibration, verification, and evaluation of the integrated watershed and receiving water model developed to model fecal coliform (FC) bacteria loading, fate, and transport in Sinclair and Dyes Inlets, Puget Sound, WA. The integrated model consisted of a watershed model, an empirical FC loading model, and an estuarine fate and transport model that was used to simulate FC bacteria loading from streams, stormwater outfalls, shoreline runoff locations, and waste water treatment plant (WWTP) discharges to determine the impact of bacterial discharges on the water quality of the inlets. Scenarios of of bacteria loading from all known sources were simulated to support a total maximum daily load (TMDL) study of bacterial pollution for the inlets.

BACKGROUND

Under the Clean Water Act, the Washington State Department of Ecology (Ecology) has the authority to establish water quality standards for surface waters of the state and develop water quality improvement plans (also known as TMDL plans) for pollutants where the waters do not meet water quality standards. In the watershed of Sinclair and Dyes Inlets, the U.S. Navy Puget Sound Naval Shipyard & Intermediate Maintenance Facility (PSNS&IMF), U.S. Environmental Protection Agency (EPA), and Ecology worked with local stakeholders as part of Project Environmental Investment (ENVVEST) to develop a TMDL for FC bacteria (Ecology, 2008a). The 1998 Washington State 303(d) list of impaired waterbodies identified bacteria contamination in surface waters of Sinclair and Dyes Inlets and tributary streams, including Barker, Clear, Strawberry, Chico, Gorst, Olney (Karcher), and Beaver Creeks that did not meet water quality standards (Ecology, 1998). The Navy, as technical lead, designed and carried out a study that meets Ecology and EPA requirements for a TMDL. First, a technical study was completed to assess FC sources and identify pollutant transport mechanisms within the watershed (May et al., 2005) then the modeling study (reported herein) was conducted to establish the capacity of the two inlets to accept discharges of FC bacteria from streams, stormwater outfalls, sewage treatment plants, and surface runoff, and still meet Washington State's water quality standards for shellfish harvesting.[1]

TECHNICAL APPROACH

A watershed model consisting of 15 Hydrologic Simulation Program Fortran (HSPF) submodels was deployed to simulate watershed hydrology for streams (open channel flows), stormwater catchments areas (piped flows), and shoreline drainage areas (overland flows) within the watershed (Skahill and Lahatte, 2007). An empirical model developed from sampling data gathered from the watershed (May et al., 2005) was used to estimate FC concentrations in surface streams and stormwater outfalls as a function of upstream land use and land cover (LULC). Flow and FC concentrations for discharges from WWTPs were estimated by interpolating data reported on monthly discharge monitoring reports (DMRs) submitted by each facility. A curvilinear hydrodynamics in three dimensions (CH3D) model, previously calibrated to match the hydrodynamics of the inlets and modified to include FC kinetics (CH3D-FC) (Wang and Richter,

[1] To protect shellfish harvesting, fecal coliform bacteria levels must not exceed a geometric mean value of 14 colonies/100 mL [Part I], and not have more than 10 percent of all samples (or any single sample when less than ten sample points exist) obtained for calculating the geometric mean value exceeding 43 colonies/100 mL [Part II] (WAC 173-201A-210).

1999, Wang et al., 2005), was used to simulate the release, transport, and fate of FC loading from watershed pour points corresponding to 39 stream mouths, 44 stormwater outfalls, 4 WWTP discharges, and 44 shoreline drainage areas.

The output from HSPF was used as input to CH3D-FC. The time-varying flows produced by HSPF for each of the stream, stormwater, and shoreline pour points were read into CH3D-FC along with the loads from the WWTPs. The estuarine CH3D-FC model was run to simulate the tides, circulation conditions, freshwater, and FC inputs occurring during individual storm events (10 d) and over the course of Water Year 2003 (WY2003) from 1 October 2002 to 30 September 2003 (364 d).

MODEL EVALUATION

We developed criteria to evaluate model performance and assess the ability to simulate watershed hydrology, FC loading, and fate and transport of FC within the inlets. We evaluated the watershed model by comparing the performance of the individual models in reproducing observed hydrologic data during the verification exercise and rating their performance. The rating was based on the Nash–Sutcliff (NS) and R^2 regression coefficients obtained between observed and predicted data and on professional judgment. Based on the available data, we were very confident that the watershed submodels could simulate watershed-scale hydrology of the Sinclair and Dyes Inlets watershed with GOOD-to-EXCEPTIONAL accuracy for streams and shoreline segments and FAIR-to-GOOD accuracy for stormwater basins.

We assessed the uncertainty and confidence in estimating the FC loading concentration for the watersheds in Sinclair and Dyes Inlets as a function of upstream LULC by comparing the overall predictions to data collected from January 2000–September 2003 (2000–2003) and October 2002–September 2003 (WY2003). Overall, we found that the statistical models reliably predicted the FC concentrations in streams within the limits of the uncertainty associated with the actual data, therefore we had a high degree of confidence in these predictions. The ability to obtain estimates of FC sources, without extrapolation, from the other drainage basins for which no data were available was another benefit. There was more uncertainty with the estimates of FC concentrations in stormwater systems; however, the stormwater approach was practical, took advantage of the available information, and provided a reasonable estimate of FC concentrations in stormwater systems.

We evaluated how well the watershed model predicted FC loading from the streams and stormwater outfalls by comparing the observed load to the simulated load. The observed and simulated mean, median, and mode of the FC loads were calculated for each watershed. The mean was used to evaluate the central tendency, the median evaluated the 50th percentile, and the mode represented the most frequent value of the observed and simulated data sets. The mean and median were compared by dividing the simulated mean and median by the observed statistic and scoring the result. Our evaluation showed that there was GOOD-to-EXCELLENT agreement with observed data for most watersheds, which increased our confidence of accurately simulating watershed-wide FC sources into the receiving waters of the inlets. However, we also identified a tendency to under-predict loads from discharges in certain areas, namely Strawberry and Mosher Creeks in Dyes Inlet; stormwater discharges into Oyster Bay and Phinney Bay; the waterfront areas around the shipyard, Bremerton, and Port Orchard in Sinclair Inlet; and Beaver Creek in Clam Bay.

We verified the CH3D-FC model by comparing model predictions to observed data collected during three storm events sampled in 2004 and data collected throughout WY2003. For the 2004 storm events, ambient marine samples were collected 12-24 hours after the storm event. The

simulation results of the 2004 storm events showed that the integrated model could produce plausible results with relatively high accuracy for major portions of the model domain. While there were mismatches between model predictions and observations at some locations, the integrated model appeared to be quite capable of simulating storm runoff and FC loading during storm events.

The WY2003 simulation was conducted to simulate FC loading over a yearly time cycle, determine the critical conditions for FC loading, compare to observed data collected over the year, and simulate scenarios required for the TMDL. Canary nodes, consisting of nine contiguous cells, were defined at specific locations within the model domain. The canary nodes represented "coal mine canaries," defined to be protective of water quality conditions at critical locations in the inlets for which observed data were also available. Simulated data from the canary nodes were used to compare model output to observed data from sample locations and evaluate water quality standards. Based on the comparison to observed data, we were confident that CH3D-FC could simulate FC fate and transport in the inlets. There was GOOD-to-EXCELLENT agreement between model predictions and observed data for marine waters; however, there was a tendency of the model to underpredict FC concentrations in certain nearshore areas, including the mouths of Clear and Strawberry Creeks, in Oyster Bay, near the mouth of Dee Creek, along the Port Orchard waterfront, and along the southern shore of Bainbridge Island.

SENSITIVITY AND UNCERTAINTY

The sensitivity analysis showed that the most important factors affecting the distribution of FC in the inlets were the FC loading, which was controlled by the loading concentration and freshwater flows, physical mixing, and FC die-off. Wind and small changes to freshwater flows did not appear to have much effect on the FC distribution in the inlets.

The effect of future build-out, or land development, on FC loading showed that expanded build-out would likely increase the frequency, magnitude, extent, and duration of FC levels exceeding water quality standards throughout the watershed. The futures analysis assumed that the modeling system developed to represent present conditions was also applicable to a future build-out and that the relationships between LULC and modeled flow and LULC and predicted FC concentrations would still be valid under future conditions. The uncertainty associated with the futures analysis lessens the confidence that can be placed in the results of the future predictions because the future is unknown. However, it is likely that any actions that effectively eliminate or reduce present problems would also be effective in addressing future problems. Such actions may include the initiatives taken by municipalities to comply with the National Pollutant Discharge Elimination System (NPDES) Phase II municipal stormwater requirements, including illicit discharge detection and removal, increased street sweeping, stormwater system maintenance improvements, and public education and outreach programs.

There are uncertainties and limitations to what the model can simulate. The model indirectly accounts for sources from failed septic systems, leaking sewer infrastructure, and upland waterfowl and wildlife only to the extent that these sources contributed to the empirical data used to develop the FC loading concentration estimates. Potential sources of FC not in the model included marinas, recreational and commercial boating, broken pipes, combined sewer overflow (CSO) events, sediment resuspension, regeneration of bacteria spores, nearshore waterfowl, marine mammals, and any other unknown sources.

TMDL SIMULATIONS

Simulations were conducted to support load and waste load allocations for the FC bacteria TMDL. The model was run to simulate “actual conditions” for WY2003 to identify areas that exceeded water quality standards. Simulations of WY2003 were conducted to calculate waste load and load allocations for streams, stormwater outfalls, and WWTPs for Part I of the standard by setting the streams and stormwater outfalls to 100 cfu/100 ml and WWTPs to 200 cfu/100 ml. Waste loads and load allocations for Part II of the standard were simulated by setting the streams and stormwater outfalls to 200 cfu/100 ml and WWTPs to 400 cfu/100 ml. Additionally, the geomean and 90^{th} percentile calculated for observed data from WY2003 for each canary node were compared to Parts I and II of the standard. The results showed that reductions would be required to meet water quality standards near the mouths of Barker, Clear/Strawberry, Gorst, Blackjack, and Olney Creeks; the area including Anderson Cove and the Pine Rd outfall draining East Bremerton in the Port Washington Narrows; and along the south shore of Bainbridge Island.

CONCLUSIONS

Based on the simulation results, we were confident that the watershed submodels could simulate watershed-scale hydrology of the Sinclair and Dyes Inlets watershed with GOOD-to-EXCEPTIONAL accuracy for streams and shorelines and FAIR-to-GOOD accuracy for stormwater basins. We were also highly confident that the hydrodynamic tides and currents were simulated by CH3D with very good accuracy for most of the inlets. The k-cluster regression used to predict FC loading based on upstream land use and cover and runoff from watershed resulted in GOOD-to-EXCELLENT agreement with observed data for streams, with the added benefit of being able to obtain estimates of FC sources, without extrapolation, from the other drainage basins for which no data were available. The loading estimates for the WWTPs derived from DMRs adequately captured the variation and magnitude of the discharges and provided a good estimate of FC loading from these sources.

Overall, the integrated watershed-receiving water model performed very well. The integrated model was able to recreate a wide range of dynamic loading within the inlets, from large-scale storm events with high flow conditions to dry, low-flow conditions during the summer months. Although data were limited for many of the stations in Sinclair Inlet, especially near the shipyard and other areas likely to receive stormwater runoff from Bremerton and Port Orchard, the model reproduced FC loading episodes with a high degree of accuracy. We were very confident that the model could simulate watershed-scale FC loading, fate, and transport in the inlets, and the stakeholder group deemed that the predictions were acceptable within the limitations identified. The integrated watershed monitoring and modeling approach to water quality management is assisting the development of management plans worthy of stakeholder acceptance, helping to achieve reductions in FC loading, and resulting in improvements to the environmental quality of the inlets.

CONTENTS

FIGURES

TABLES

ACRONYMS AND ABBREVIATIONS

ADCP	Acoustic Doppler Current Profiler
AGWETP	Fraction of ET (evapotranspiration) Taken from Groundwater
AGWO	Baseflow Runoff
AGWRC	Groundwater Recession Parameter
ANOVA	Analysis of Variance
ARA	Antibiotic Resistance Analysis
ARCC	Average Rate of Correct Classification
ARM	Agricultural Runoff Management
BASINS	Better Assessment Science Integrating Point and Nonpoint Sources
B-IBI	Benthic Index of Biological Integrity
BMP	Best Management Practice
BMSL	Battelle Marine Sciences Laboratory
BOD	Biological Oxygen Demand
BST	Bacteria Source Tracking
CD	Compact Disk
CF	Coniferous Forest Cover in Watershed
CFB100	Coniferous Forest Cover in 100 M Buffer along Streams
CFR	Code of Federal Regulations
cfs	Cubic Feet per Second
cfu	Colony Forming Units
CH3D	Curvilinear Hydrodynamics in 3 Dimensions (marine model)
CH3D-FC	CH3D Model with FC Kinetics Module
CI	Commercial/Industrial Landuse in Watershed
COB	City of Bremerton
COBI	City of Brainbridge Island
COC	Contaminants of Concern
COD	Chemical Oxygen Demand
CPO	City of Port Orchard
CSO	Combined Sewer Overflows
CTC	Concurrent Technologies Corporation
COV	Coefficient of Variation
CWA	Clean Water Act
DEEPFR	Fraction of Groundwater Inflow that Goes to Inactive Groundwater
DEM	Digital Elevation Model
DMR	Discharge Monitoring Report
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
DSN	Data Set Number (used in HSPF for each watershed represented in the model)
EC	Enterococcus
Ecology	Washington State Department of Ecology
ENVVEST	Environmental Investment
EPA	Environmental Protection Agency
ERDC	U.S. Army Engineering Research and Development Center
ET	Evapotranspiration
ETF	City of Bremerton Eastside Treatment Facility

FC	Fecal Coliform
FIB	Fecal Indicator Bacteria
FPI	Fecal Pollution Index
FPOM	Fine Particulate Organic Matter
FSL	Forecast Systems Laboratory
GAS	Growing Area Standard
GIS	Geographic Information System
GPS	Global Posistioning System
HD	High-Density Residential Land Use
HEC	Hydrologic Engineering Center
HL	Grass or Turf Cover in Watershed
HSPF	Hydrologic Simulation Program–FORTRAN (watershed model)
IFWO	Interflow Runoff
IMP	Percent Impervious Land Cover/ Percent Effective Impervious Area
IMPLND	Impervious Land Cover
INFILT	Interflow Inflow Parameter (related to infiltration capacity of the soil)
INSUR	Manning’s N for the Imperivous Overland Flow Plane
INTFW	Interflow Inflow Parameter
IRC	Interflow Recession Parameter
I-SURO	Impervious Surface Runoff
I-TAET	Impervious Surface Total Evapotranspiration
KC-DCD	Kitsap County Department of Community Development
KCHD	Kitsap County Health District
KC-SSWM	Kitsap County Surface And and Storm water Water Management Department
KPUD	Kitsap Public Utility District
LA	Load Allocation
LD	Rural (Low Density Residential) Land Use in Watershed
LH-PCR	Length Heterogeneity-Polymerase Chain Reaction
LID	Low Impact Development
LULC	Land Use and Land Cover
LZETP	Lower Zone ET Parameter (an index of the density of deep-rooted vegetation)
LZSN	Lower Zone Nominal Storage
m	Meter
MD	Medium-Density Suburban (MD Residential) Land Use in Watershed
MESC	Marine Environmental Survey Craft
MF	Membrane Filtration (technique used for fecal coliform analysis)
MOS	Margin of Safety
MPN	Most Probable Number
MST	Microbial Source Tracking
NBK	Naval Base Kitsap
NCDC	National Climatic Data Center
NEDS	Northwest Environmental Database System
netCDF	Network Common Data Format
NPDES	National Pollutant Discharge Elimination System
NPS	Nonpoint Source
NR	Not Reported
NRCS	Natural Resources Conservation Service

NS	Nash-Sutcliff Statistic
NSSP	National Shellfish Sanitation Program
NSUR	Manning's N for Overland Flow
NURP	National Urban Runoff Program
NWS	National Weather Service
OBM	Optical Brightener Monitoring
OWTS	Onsite Waste Treatment System (septic tank)
PAHs	Polynuclear Aromatic Hydrocarbons
PAM	Polyacrylamide
PAR	Photosynthetically Active Radiation
PC	Personal Computer
PCBs	Polychlorinated Biphenyls
PCR	Polymerase Chain Reaction
PERLND	Pervious Land Cover
PEST	Parameter Estimation and Optimization Software Tool
PFGE	Pulsed Field Gel Electrophoresis
PIC	Pollution Identification and Correction
PNNL	Pacific Northwest National Laboratory
POTW	Publicly-Owned Treatment Works
PSNS	Puget Sound Naval Shipyard
PSNS&IMF	Puget Sound Naval Shipyard & Intermediate Maintenance Facility
PSU	Practical Salinity Units
QA/QC	Quality-Assurance/Quality-Control
RD	Road Density-Length of Roads/Area of Watershed (kKm/kKm^2)
RETSC	Retention (interception) Storage Capacity of the Impervious Surface
RNA	Ribosomal Ribonucleic Acids
RPD	Residual Percent Difference
SC/SL	Ratio Of Stream Crossings to Stream Length within Watershed (#/Km)
SCCWRP	Southern California Coastal Water Research Project
SCS	Soil Conservation Service
SGA	Shellfish Growing Area
SPAWAR	Space and Naval Warfare Systems Command
SSC Pacific	Space and Naval Warfare Systems Center Pacific
SSO	Storm Sewer Overflows
SSWM	Surface and Stormwater Management
SURO	Surface Runoff
TAET	Total Evapotranspiration
TEC	The Environmental Company Inc.
TIA	Total Impervious Area
TM	Thematic Mapper (satellite imaging system deployed on Landsats 4 and 5)
TMDL	Total Maximum Daily Load
TSS	Total Suspended Solids
U/I	Urban or Industrial Stormwater Outfalls
UCI	User Control Input
USACE	U.S. Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey

USLE	Universal Soil Loss Equation
UV	Ultraviolet
UZSN	Upper Zone Nominal Storage
WA-DOE	Washington State Department of Ecology
WA-DOH	Washington State Department of Health
WASP	Water Quality Analysis Simulation Program
WDM	Watershed Data Management (file created and used by HSPF)
WES	Waterways Experiment Station
WLA	Waste-Load Allocation
WMS	Watershed Modeling System
WQ-ID	Water Quality Monitoring Station Identifier
WQS	Water Quality Standards
WRIA	Water Resource Inventory Area
WWTP	Waste Water Treatment Plant
WY	Wateryear (1 October through 30 September)

1. INTRODUCTION

1.1 Background

Under the Clean Water Act, the Washington State Department of Ecology (Ecology) has the authority to establish water quality standards for surface waters of the state and develop water quality improvement plans (Total Maximum Daily Load [TMDL] plans) for pollutants where the waters do not meet water quality standards. The 1998 Washington State 303(d) list identified exceedances due to bacteria contamination in surface waters of the Sinclair and Dyes Inlets watershed. Impairments were listed for Sinclair and Dyes Inlets and tributary streams, including Barker, Clear, Strawberry, Chico, Gorst, Olney (Karcher), Dee, and Beaver Creeks (Ecology, 1998). The pollution resulted in the loss of beneficial uses of the water bodies for swimming and shellfish harvesting.

In September 2000, the Puget Sound Naval Shipyard & Intermediate Maintenance Facility (PSNS&IMF), the U.S. Environmental Protection Agency (EPA), and Ecology entered into an environmental investment (ENVVEST) partnership to develop and demonstrate alternative strategies for protecting and improving the ecological integrity of Sinclair and Dyes Inlets and their surrounding watershed in the Puget Sound, Washington (U.S. Navy, U.S. EPA, Ecology, 2000). As part of Project ENVVEST, a cooperative study among PSNS&IMF, Ecology, and other technical stakeholders was initiated to develop a fecal coliform (FC) bacteria TMDL for the inlets and tributary streams (ENVVEST, 2002; Johnston et al., 2004). The TMDL will establish the capacity of the two inlets to accept discharges of FC bacteria from streams, stormwater outfalls, waste water treatment plants (WWTPs), and surface runoff, and still meet water quality standards.

A technical assessment was completed to identify microbial pollution problems within the watershed and to provide a comprehensive assessment of microbial pollution from all identifiable sources (May et al., 2005). In addition to data collected during the study period from Spring 2001 to Summer 2005, the assessment relied on historical data collected by the Kitsap County Health District (KCHD, 2002, 2003, 2004, 2005), the Washington State Department of Health (WDOH) (Determan, 2001, 2003; WDOH, 2003a, 2005a,b), and Kitsap County Surface and Storm Water Management (SSWM) (SSWM, 2002a, b).

The assessment (May et al., 2005) reported numerous sources of bacterial pollution in the watershed that could impact water quality and shellfish harvesting areas. In general, microbial pollution was higher in subwatersheds with greater population densities, in areas with a greater percentage of impervious area, and in areas served by older sewer infrastructures or onsite sewage treatment (septic) systems. Water quality standards for bacteria were more likely to be exceeded in streams with higher stormwater inputs and in stream draining areas with more development. Increased bacterial pollution levels were also more likely following major storm events because of increased stormwater runoff entering marine waters via streams and stormwater outfalls. Elevated bacterial pollution levels in nearshore areas appeared to be localized and persisted for only a short period after storm events or during extended periods of rainfall. However, elevated chronic bacterial pollution was persistent in some nearshore and estuarine areas where shoreline development was intense or where urbanized streams and stormwater outfalls were common. Microbial pollution levels found during storm season sampling were about 10 times higher than those for non-storm periods, especially for nearshore sites adjacent to highly urbanized drainage basins. Investigations of the

relationship between bacterial pollution and land use showed that the loss of natural forest cover and the increase in impervious surfaces associated with suburban and urban levels of development were significantly correlated with pollution levels and exceeding water quality standards (May et al., 2005).

In support of the FC TMDL study for the inlets and tributary streams, we report on an integrated modeling study conducted to simulate runoff and transport of FC bacteria from the watershed surrounding Sinclair and Dyes Inlets.

1.2 Study Area

Located along the west side of Central Puget Sound, Sinclair and Dyes Inlets are connected by the Port Washington Narrows and joined to the main basin of the Puget Sound by Port Orchard, Agate, and Rich Passages (Figure 1-1). Tides propagate from the ocean and enter the inlets from Port Orchard and Agate Passage to the north and Rich Passage in the southeast. The watershed drains about 62,348 acres (25,231 hectares, 97.6 square miles) and includes portions of Kitsap County, the cities of Bremerton and Port Orchard, and the southwestern end of Bainbridge Island. Major streams draining into the inlets include Chico, Clear, Blackjack, and Gorst Creeks, as well as a number of smaller streams and stormwater conveyance systems located within the developed areas of East and West Bremerton, Silverdale, Port Orchard, and Bainbridge Island (Figure 1-1).

Presently, native forests cover about half of the watershed, but the forests are mostly concentrated in a few undeveloped watersheds (e.g., Chico and Gorst watersheds). The remainder of watershed is developed, and development is present in all watersheds and along the shoreline of the inlets. Most of the impervious surfaces are located in the urban centers of Bremerton, Silverdale, the Naval Base Kitsap–Bremerton (NBK) and Puget Sound Naval Shipyard & Intermediate Maintenance Facility (PSNS&IMF), and areas in and around Port Orchard. Most of the impervious surfaces that are not drained by streams are shoreline urban areas predominantly located in West Bremerton, portions of East Bremerton, Port Orchard, and Silverdale (May et al., 2004).

The Kitsap Peninsula enjoys a cool, maritime climate that is mediated by the Cascade and Olympic mountain ranges with average temperatures ranging from about 70 °F (21.1 °C) in the summer to 40 °F (4.4 °C) in the winter (NOAA, 2007). The annual rainfall in Bremerton between water years (WY) 2000–2006 ranged from 34.3–53.25 inches, with 41.5 inches occurring during WY2003 (1 October 2002 to 30 September 2003) (City of Bremerton, 2007). Most of the precipitation (85%) occurs between October and April. The marine waters of Sinclair and Dyes Inlets range from 9.6–10.0 °C (49.3–50.0 °F) in winter to 18.2–20.7 °C (64.6–69.2 °F) in summer, and the salinity range is 28.0–30.3 Practical Salinity Units (PSU) and 28.5–30.0 PSU for Sinclair and Dyes Inlets, respectively (Albertson et al., 1993).

Tides in the Puget Sound region are semi-diurnal and diurnal mixed modes with two high and two low tides every diurnal cycle (24.8 hours). Once reaching the entrances to the two passages and into the inlets, the tides are further modulated in a nonlinear fashion by a number of forcing mechanisms, including freshwater inflows, wind, water-depth variations and waterbody geometry. Tidal flows in the inlets are modulated both spatially and temporally; with maximum tidal ranges (from low tide to high tide) reaching 5.5 m during spring tides (Wang and Richter, 1999).

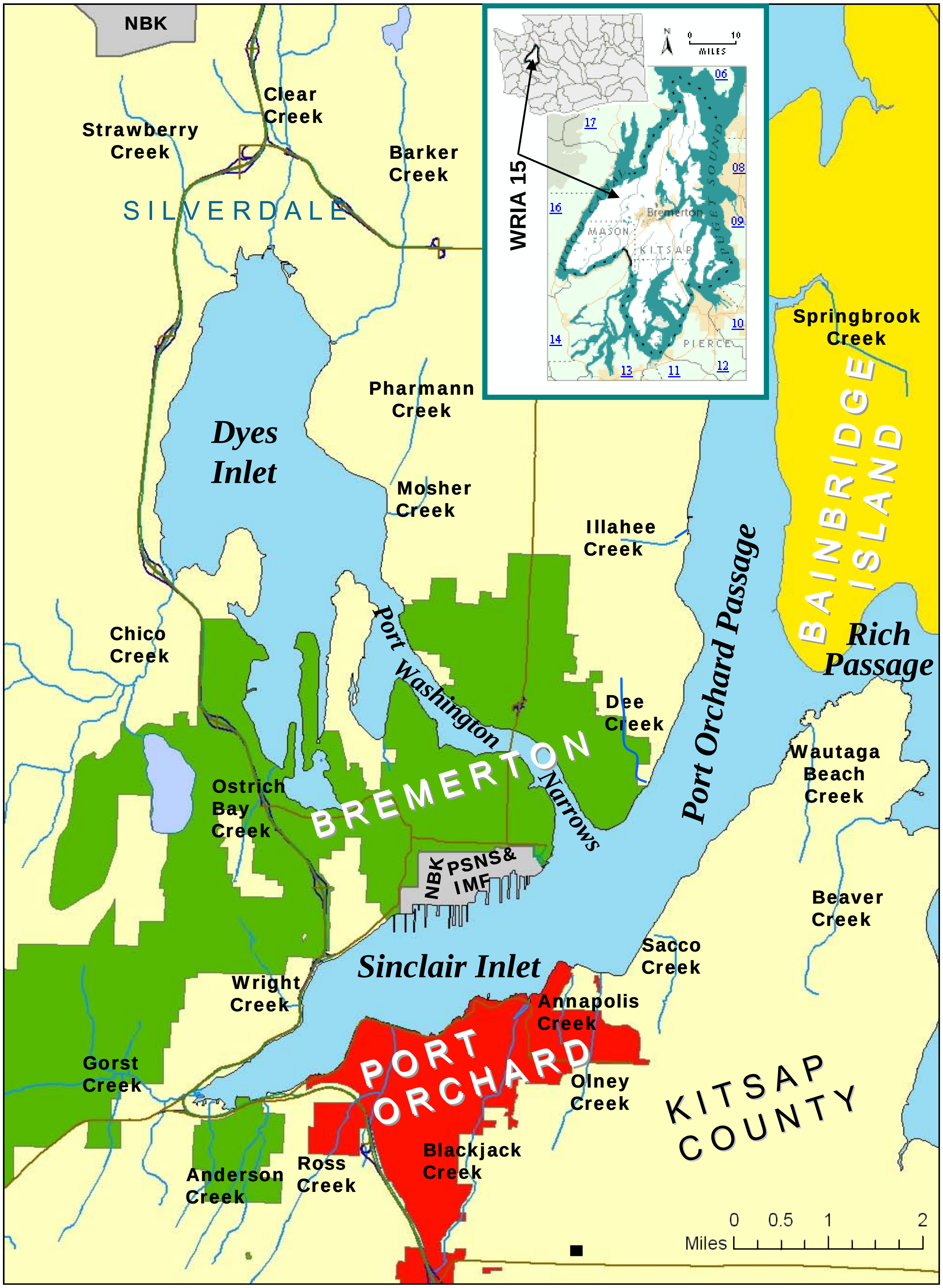


Figure 1-1. Sinclair and Dyes Inlets, Port Washington Narrows, Port Orchard and Rich Passages, and major streams in the watershed.

1.3 Technical Approach

In this report we document the development, calibration, verification, and evaluation of the integrated watershed and receiving water model developed for the Sinclair and Dyes Inlets Watershed (Figure 1-1). Simulation results are also reported for specific simulations conducted to support load and waste load allocations for an FC bacteria TMDL study conducted for the inlets.

Watershed models for all the stream, stormwater, and shoreline catchments in the watershed were developed using the Hydrologic Simulation Program-FORTRAN (HSPF), (Skahill, 2004, 2005; Skahill and LaHatte, 2006, 2007). The objective of the watershed modeling was to provide watershed-scale simulations of hydrology to predict runoff from all streams, shoreline areas, and engineered drainage systems (stormwater outfalls) draining into Sinclair and Dyes Inlets to model freshwater and pollutant input into the inlets.

An empirical model developed from sampling data gathered from the watershed (May et al., 2005) was used to estimate FC concentrations in surface streams, shoreline drainage areas, and stormwater outfalls as a function of upstream land use and land cover (LULC). Flow and FC concentrations for discharges from waste water treatment plants (WWTP) were estimated by interpolating data reported on monthly discharge monitoring reports (DMRs) submitted by each facility. A curvilinear hydrodynamics in three dimensions (CH3D) model, previously calibrated to match the hydrodynamics of the inlets and modified to include FC kinetics (CH3D-FC) (Wang and Richter, 1999; Wang et al., 2005) was used simulate the release, transport, and fate of FC loading from watershed pour points corresponding to 39 stream mouths, 44 shoreline drainage areas, 58 stormwater outfalls, and 4 WWTP discharges.

The output from HSPF was used as input to CH3D-FC. The time varying flows produced by HSPF for each of the stream, stormwater, and shoreline pour points were read into CH3D-FC along with loads from the WWTPs. The estuarine CH3D-FC model was run to simulate the tides, circulation conditions, freshwater, and FC inputs occurring during individual storm events (10 d) and over the course of Water Year 2003 (WY2003) from 1 October 2002 to 30 September 2003 (364 d).

We compared the output of the integrated model to observed data to verify model performance and identify limitations and uncertainties in the model's predictions. Sensitivity analysis was conducted to evaluate the sensitivity of model predictions to specific sets of input parameters, including FC loading concentration, stream and stormwater flow, wind, and FC bacterial die-off. The uncertainty analysis assessed the effects of future growth and development on the amount FC bacteria that would be released into the inlets.

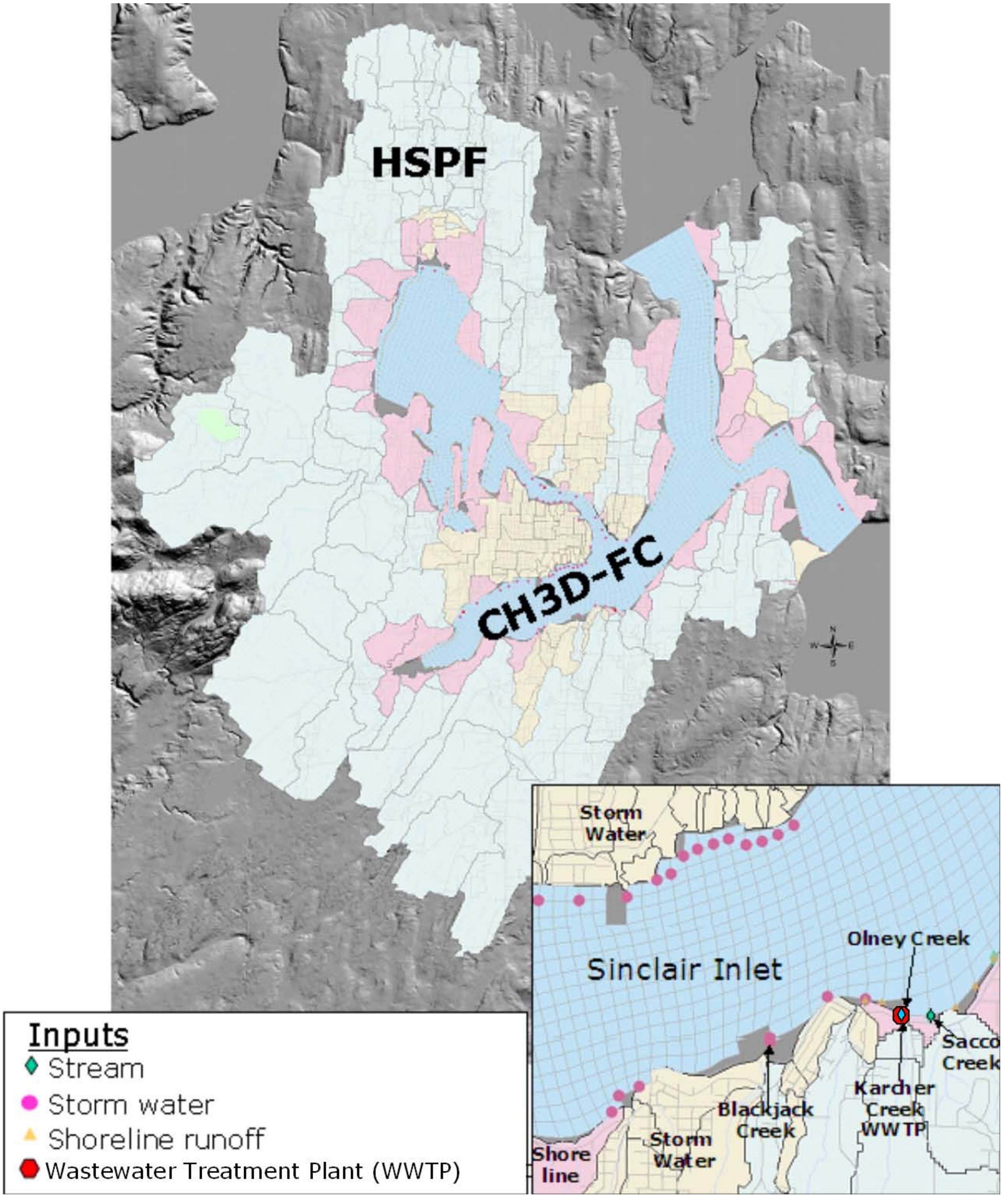


Figure 1-2. The integrated watershed receiving water model developed for Sinclair and Dyes Inlets showing the extent of the watershed model for streams (green watersheds), shorelines (pink watersheds), and stormwater outfalls (yellow watersheds) modeled by HSPF, the numerical grid of the receiving waters modeled by CH3D-FC, and detail of model inputs (inset).

We also conducted simulations to support load and waste load allocations for the FC bacteria TMDL. The model was run to simulate “actual conditions” for WY2003 to identify areas that exceeded water quality standards. Simulations of WY2003 were conducted to calculate waste load and load allocations for streams, stormwater outfalls, and WWTPs. Loading required to meet Part I of the standard was evaluated by setting the streams and stormwater outfalls to 100 cfu/100 ml and WWTPs to 200 cfu/100 ml. Waste loads and load allocations for Part II of the standard were simulated by setting the streams and stormwater outfalls to 200 cfu/100 ml and WWTPs to 400 cfu/100 ml. Additionally, the geomean and 90th percentile calculated for observed data from WY2003 for each canary node were compared to Parts I and II of the standard.

1.4 About this Report

In this report we summarize a large body of work that went into collecting and analyzing data, deploying, calibrating, and verifying the models, and conducting specific simulations to inform the TMDL process. The details of this work are reported in supporting documents referenced in the bibliography complete with internet links (if available) and additional supplemental information is provided on the distribution CD or or via the internet (Table 1-1). Data and model information can also be accessed with the ENVVEST Spatial Viewer available via the internet (Table 1-1).

Section 2 describes the model development including the deployment and calibration of the HSPF watershed models, the derivation of empricial preditictions for FC loading concentrations of stream, shoreline, and stormwater discharges, and the setup and calibration of the CH3D-FC model to simulate the fate and transport of FC bacteria in Sinclair and Dyes Inlets. Section 3 outlines how the watershed and FC loading concentration models were coupled to CH3D-FC to create the integrated watershed/receiving water model and Section 4 documents model verification and provides the results of sensitivity and uncertainty simulations. The TMDL simulation results are provided in Section 5 and the conclusions of the study are summarized in Section 6. Additional supplemental information is provided on the distribution CD and is also available via the internet (Table 1-1).

Table 1-1. Summary of supplemental information available on the distribution CD and via the internet.

Supplemental information available on the distribution CD or via the internet at http://environ.spawar.navy.mil/Projects/ENVVEST/FC_Model_Report/

HSPF model	**Sensitivity Analysis**
Reports	**FC Loading**
Input Files	**Wind**
Calibration and Verification Results	**Flow**
CH3D-FC Model	**FC Die-Off**
Reports	**Uncertianty Analysis**
Input files	**Future Expanded Build Out Reduced Buffer**
Calibration and Verification Results	**Future Expanded Build Out Same Buffer**
Integrated Model Simulation Results	**Furture Expanded Build Out Full Buller**
2004 Storm Events	**TMDL Simulation Results**
April 2004 Storm Event	**100/200**
May 2004 Storm Event	**200/400**
Octboer 2004 Storm Event	
WY2003 Verification	
91 x 94 grid	
94 x 106 grid	
WY2003 Critical Conditions	

Supplemental information accessible with the ENVVEST Spatial Viewer at http://kairos.spawar.navy.mil/Website/spatialviewer

General Information	**Model Query**
Base Map	**S1 April 2004 25th Percentile**
Streams	**S2 April 2004 50th Percentile**
Drainage	**S3 April 2004 75th Percentile**
Roads	**S4 May 2004 25th Percentile**
Pour Points	**S5 May 2004 50th Percentile**
ENVVEST Layers	**S6 May 2004 75th Percentile**
Drainage Basins	**S7 Octobet 2004 25th Percentile**
Watersheds	**S8 October 2004 50th Percentile**
Grid 91x96	**S9 October 2004 75th Percentile**
Canary Nodes 91x96	**S10A WY2003 91x96**
Grid 94x105	**S10B WY2003 94x105**
Canary Nodes 94x105	**S11 WY2003 Critcal Conditions**
Grid 131x133	**S14 May 2004 Flow increased by 1.2**
Land Use Land Cover	**S15 May 2004 Flow increased by 2.0**
Data Query	**S16 May 2004 With Wind**
April 2004	**S17 May 2004 No FC Die-Off**
May 2004	**S18 Future Same Buffer**
Oct 2004	**S19 Future Reduced Buffer**
FC TMDL Electronic Data	**S20 Future Full Buller**

2. MODEL DEVELOPMENT

2.1 Watershed Modeling Using HSPF

We depolyed HSPF models to provide watershed-scale simulations of hydrology and predict runoff from all streams, shoreline areas, and engineered drainage systems (stormwater outfalls) draining into Sinclair and Dyes Inlets (Skahill, 2003, 2004, 2005; Skahill and LaHatte, 2006, 2007). The watershed modeling effort involved literature searches, defining data collection needs, data collection, data processing, site surveys, software development, and model implementation, calibration, verification, and prediction. A desired outcome of the modeling was to recreate the present conditions (circa 1999) within the watershed in such a way that it would be possible to model land use changes that could occur in the future. The details of this work are provided in the references cited above; here we summarize the technical approach, review the watershed modeling results, and evaluate model performance for simulating watershed-scale loading of pollutants, in this case, FC, into Sinclair and Dyes Inlets. Supplemental information about the HSPF modeling is available on the distribution CD and via the internet (Table 1-1).

2.1.1 Watershed Model Setup

We obtained specific watershed data from available geographic information systems (GIS) databases and field observations to set up, calibrate, and verify the watershed models (Table 2-1, Skahill and LaHatte, 2006). Physical data for the watershed included National Elevation Data (NED) for topography (USGS, 2004), soils data (USDA, 2004), and LULC data consisting of proprietary thematic mapper data (CTC, 2001) and national land cover data (USGS, 2004). Physical watershed data, soils data, LULC, and percent impervious data for 1999 (Figure 2-1) were used to support the model deployments (Skahill, 2004; Skahill and LaHatte, 2006). Bathymetry data and other ancillary information for Kitsap Lake, Island Lake, and Wildcat Lake were obtained from Washington Department of Fish and Wildlife (WDFW). Channel cross-sections were approximated based on field surveys and best professional judgment. Subwatersheds were delineated using landscape-scale characteristics based on the 10-meter digital elevation model (DEM), information about urban drainage systems obtained from Kitsap County and the cities of Bremerton, Port Orchard, and Bainbridge Island, and other existing data and information (Johnson et al. 2001; Skahill, 2004; 2005; Skahill and LaHatte, 2006).

Data from flow and precipitation monitoring conducted by Kitsap Public Utilities District (KPUD), City of Bremerton (COB), The Environmental Company (TEC), and PSNS&IMF were used to support HSFP model deployment, calibration, and verification (Figure 2-2) (TEC, 2003; Skahill and LaHatte, 2006). Based on available data and geographic similarities within the watershed, landscape segments were defined for parameterizing and calibrating submodels that were implemented for the watershed (Figure 2-3). The watershed was subdivided into individual land segments that were assumed to have homogeneous hydrologic and water quality responses based on geographic proximity and similar landuse patterns (Skahill and LaHatte, 2006). For the HSPF models to be capable of simulating both existing and future conditions, specific land use classes (pervious lands–PERLND) were defined within the model (Table 2-1). Developed land uses within a given modeled subwatershed were partitioned between pervious land area and directly connected impervious land (IMPLND) area based on available literature (Alley and Veenhuis, 1983) and subsequently adjusted during the calibration procedure (Skahill and LaHatte, 2006).

Table 2-1. LULC characteristics, level of development, and range of imperviousness (Alley and Veenhuis, 1983) of land use classes used in HSPF development (Skahill and LaHatte, 2006).

Land Use/Land Cover		Level of Development	Imperviousness
Medium Density Residential	MD	Medium	11% - 19%
High Density Residential.	HD	High	19% - 32%
Commercial/Industrial	CI	Commercial/Industrial	51% - 98%
Agricultural/Rural Dev.	LD	Low	7% - 10%
Herbaceous Range Land	HL		
Shrub & Brush Range Land	SB		
Deciduous Forest	DF		
Coniferous Forest	CF		
Mixed Forest	MF		
Beaches	BE		
other (Barren Land)	BL		

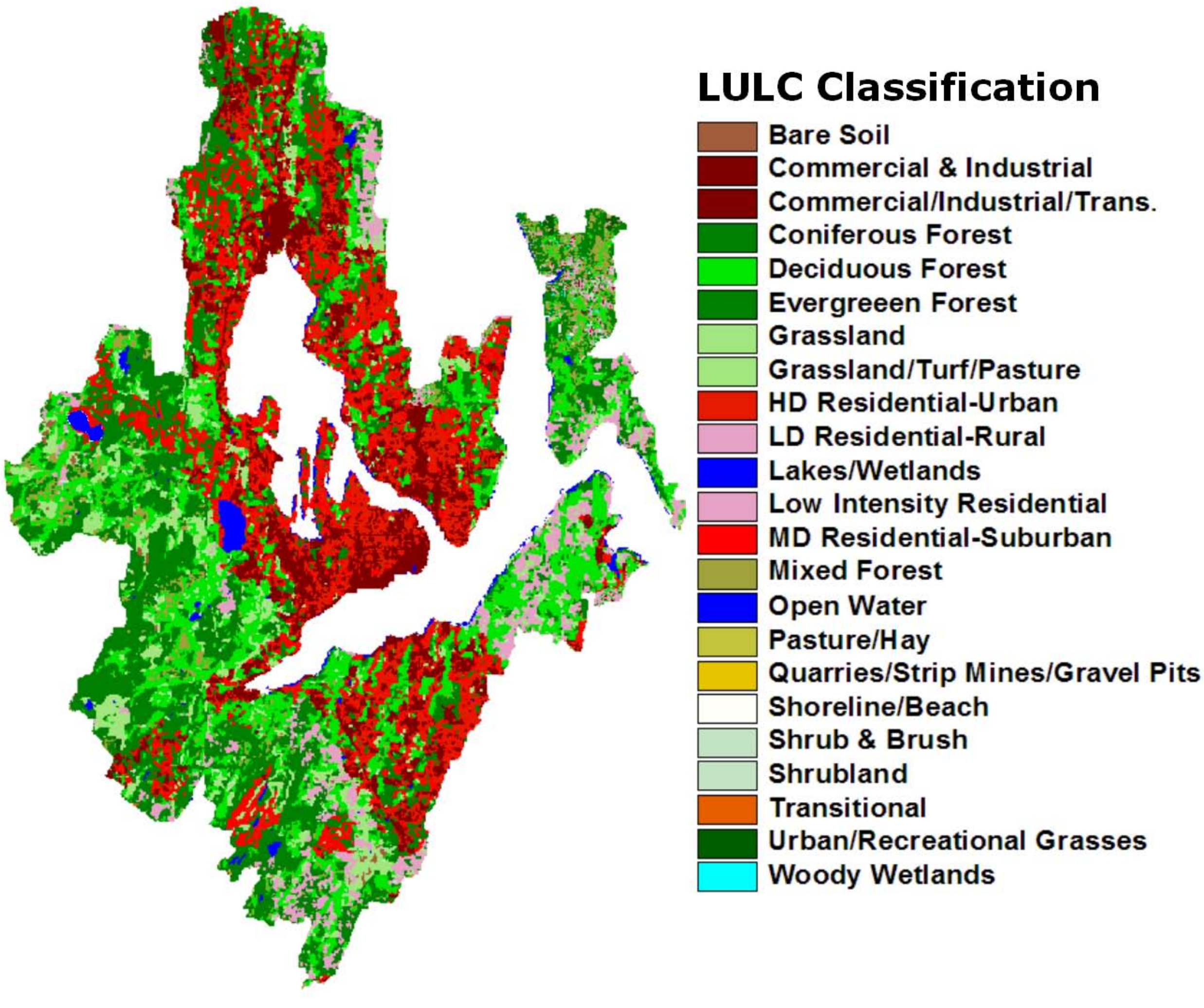


Figure 2-1. The LULC classifications based on 1999 watershed conditions inferred from a Thematic Mapper (TM) image.

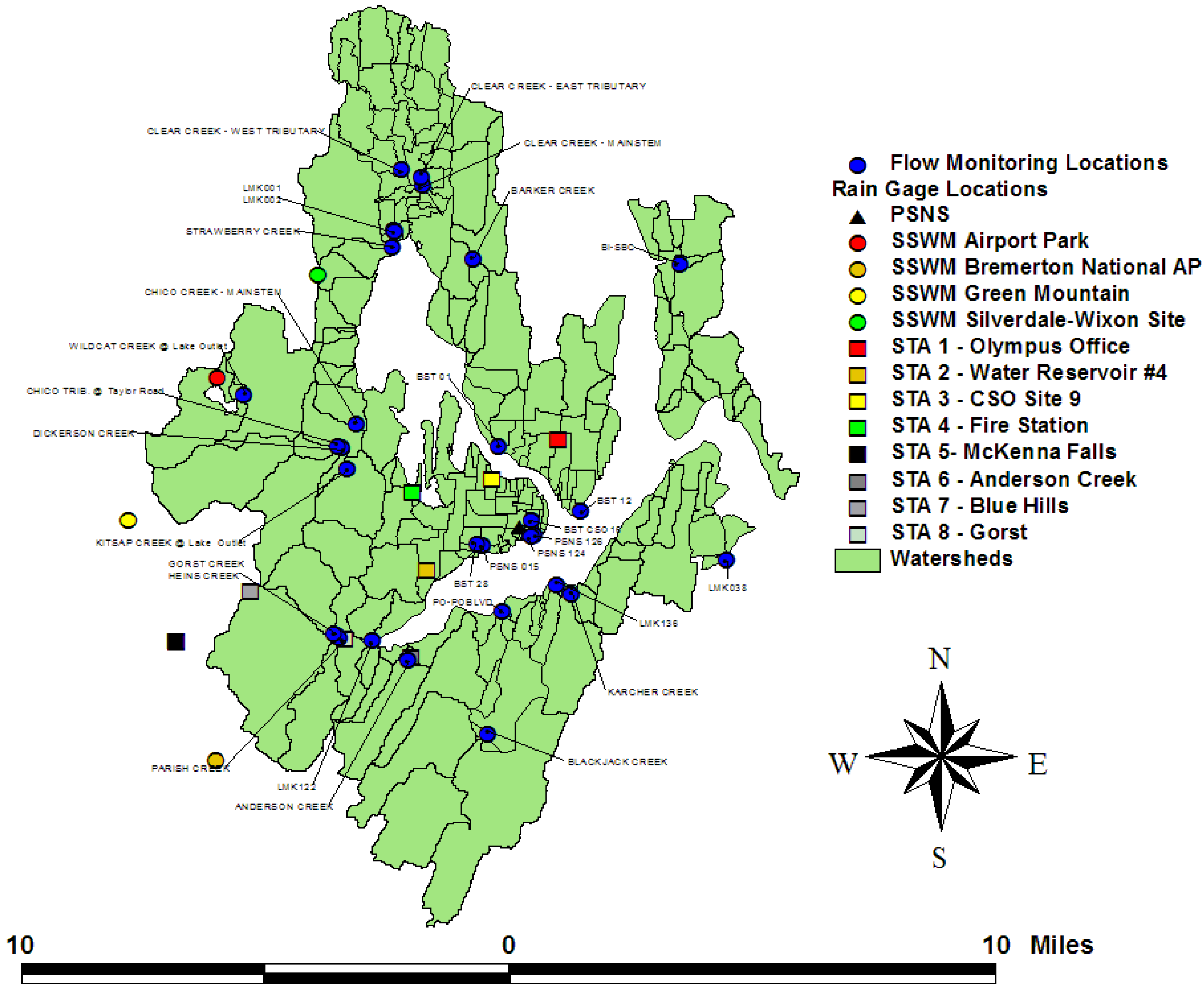
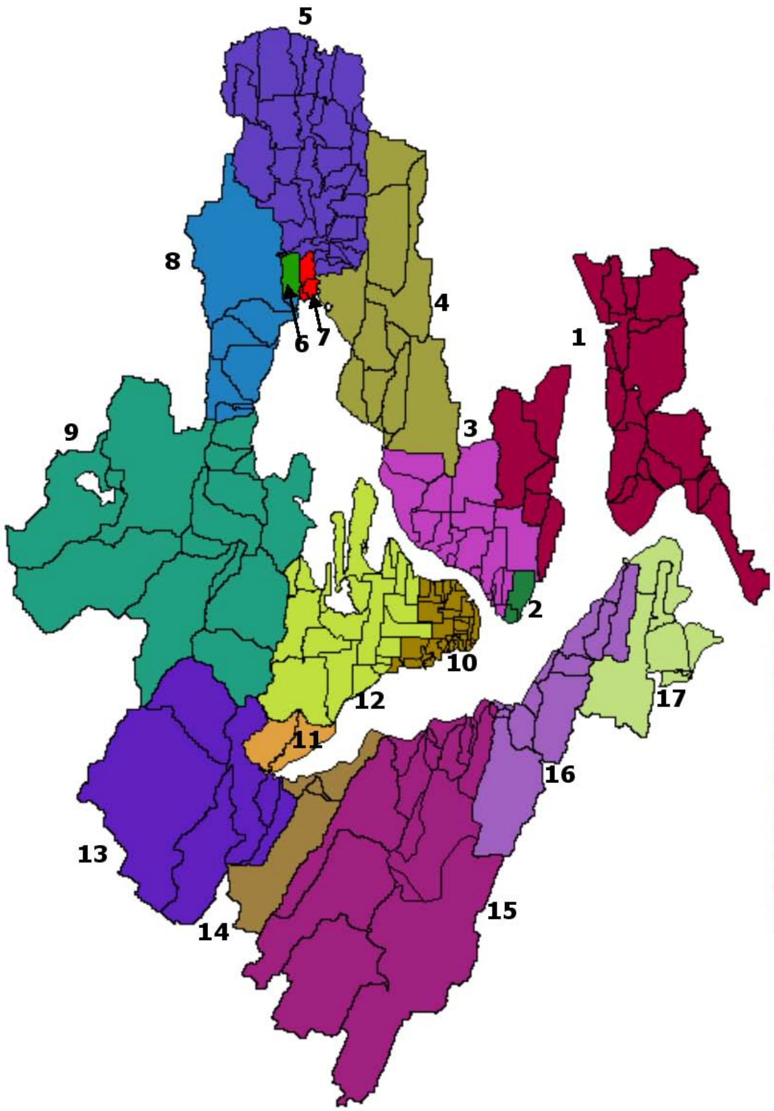


Figure 2-2. Watershed boundaries and locations of flow monitoring and rain gauging stations used to collect data to support hydrologic model deployment and calibration for the Sinclair and Dyes Inlets watershed.



Models

Segment	Model	Name
17	LMK038	Manchester
16	KARCHER	Karcher Cr.
15	BJACK	Blackjack Cr.
14	ANDERSON	Anderson Cr.
13	GORST	Gorst Cr.
12	BST28	Callow Ave
11		
10	BSTCSO16	Pacific Ave.
9	CHICO	Chico Cr.
8	STRAW	Strawberry Cr.
7	LMK002	Silverdale Bucklin Hill
6	LMK001	Silverdale Sand Piper
5	CLEAR	Clear Cr.
4	BARKER	Barker Cr.
3	BST01	Pine Rd.
2		
1	SBC	Springbrook Cr.

Figure 2-3. Delineated watersheds, landscape segments (color and number), and HSPF submodels (model name) used to model hydrologic runoff from the Sinclair and Dyes Inlets watershed. HSPF submodels BST28 and BST01 were applied to two landscape segments, e.g., 11 & 12, and 2 & 3, respectively.

2.1.2 Watershed Model Calibration

The approach we used to calibrate the HSPF models was to not only fit stream flow stage-discharge data, but also to match predetermined expectations (targets) for the partition of average annual precipitation across surface runoff (SURO), interflow runoff (IFWO), baseflow runoff (AGWO), total evapotranspiration (TAET), impervious surface runoff (I-SURO), and impervious surface total evapotranspiration (I-TAET) for each LULC represented in the models (Skahill and LaHatte, 2006). Enhancements (Skahill and Doherty, 2006) and adaptations (Doherty and Skahill, 2006) to the Levenberg–Marquardt method of computer-based parameter estimation were employed using a model-independent parameter estimation and optimization software tool (PEST, GES 2000) to calibrate the HSPF models developed for ENVVEST. Based on predefined parameter constraints (Table 2-2), the PEST software was used to minimize iteratively, quantitative measures of model-to-measurement misfit encapsulated in a "measurement objective function" defined to minimize the errors between observed data and mean annual precipitation targets and their simulated counterparts.

The models were calibrated for an identified calibration period, and the calibrated models were used to predict flows during a different verification period. Generally, based on the data available to support calibration and verification, data from WY2001–2002 were used for calibration (Figure 2-4). The calibrated models were then verified by comparing predicted flows to observed flows from WY2003 (Figure 2-5) and observed targets for the whole model and individual land use classes (Figure 2-6). The watershed model calibration and verification effort attempted, as much as possible, to incorporate conventional guidance for HSPF model calibration so as to not overly bias the models to individual storm events or isolated flow regimes.

Table 2-2. Parameters estimated during calibration of HSPF submodels (Skahill and LaHatte, 2006).

Parameter	Description	Bounds Imposed during Calibration
IMP	Percent effective impervious area (Alley and Veenhuis 1983)	11–19% for medium-density residential 19–32% for high-density residential 51–98% for commercial/industrial development 7–10% for acreage and rural residential
INSUR	Manning's n for the impervious overland flow plane	0.01–0.15
RETSC	Retention (interception) storage capacity of the impervious surface	0.01–0.3
AGWETP	Fraction of ET taken from groundwater (after accounting for that taken from other sources)	0.01–0.2
AGWRC	Groundwater recession parameter	0.833–0.999 day^{-1}
DEEPFR	Fraction of groundwater inflow that goes to inactive groundwater	0.0–0.2
INFILT	Related to infiltration capacity of the soil	0.001–1.000 in/hr
INTFW	Interflow inflow parameter	1.0–10.0
IRC	Interflow recession parameter	0.30–0.85 day^{-1}
NSUR	Manning's n for the overland flow plane	0.05–0.5
LZETP	Lower zone ET parameter - an index of the density of deep-rooted vegetation	0.1–0.9
LZSN	Lower zone nominal storage	2–15 in
UZSN	Upper zone nominal storage	0.05–2 in

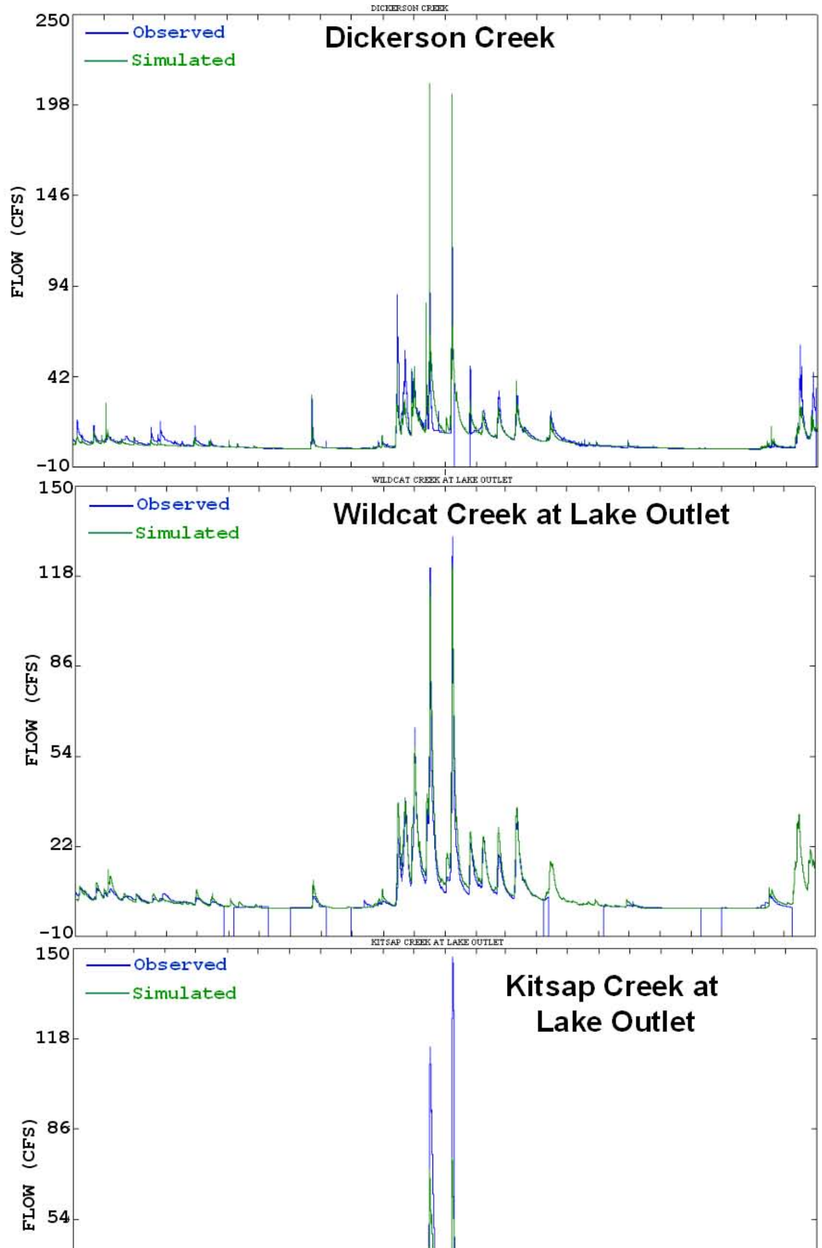


Figure 2-4. Observed and simulated 15-minute flows used for calibrating subwatersheds in the Chico Creek basin from January 2001 to December 2002.

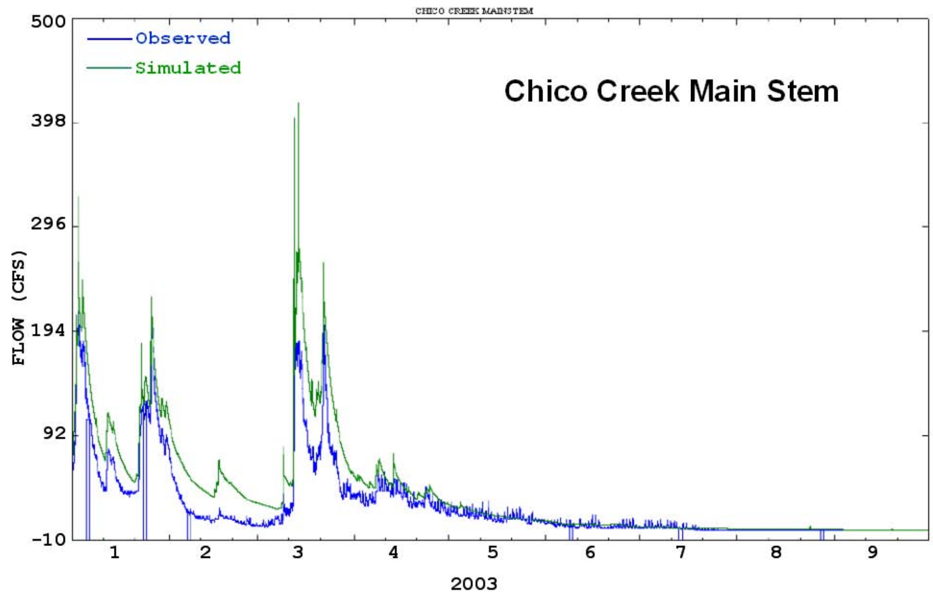
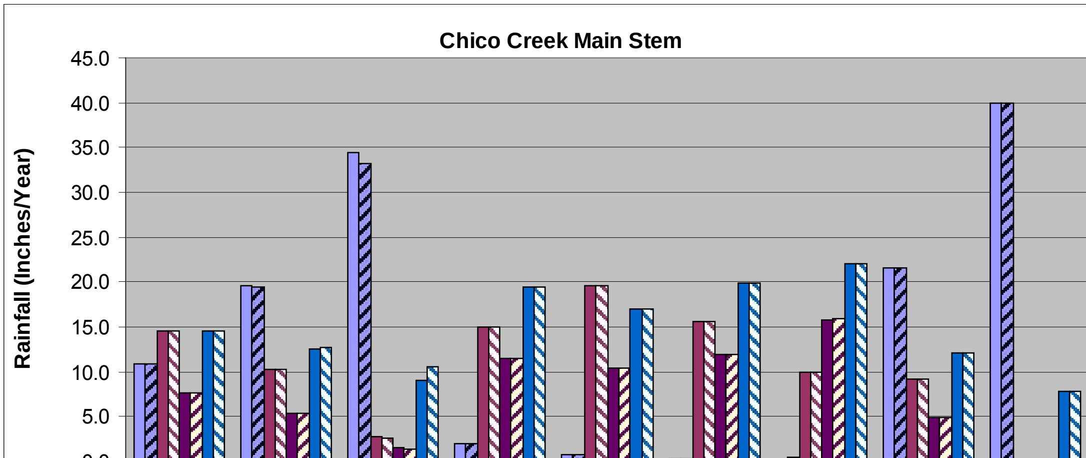


Figure 2-5. Results of HSPF model verification of Chico Creek Main Stem for observed (blue) and simulated (green) flow for 2003.



	SUBURBAN (MD)	MULTI-FAMILY (HD)	COMM (CI)	RURAL (LD)	SCHRUB (SB)	PASTURE (HL)	FOREST CF+DF+MF	BARE (BL)	IMPERV
oSURO	10.9	19.6	34.5	1.9	0.7	0.3	0.1	21.6	40.0
sSURO	10.9	19.5	33.3	1.9	0.7	0.4	0.4	21.6	40.0
oIFWO	14.5	10.2	2.8	14.9	19.6	15.6	9.9	9.2	
sIFWO	14.5	10.2	2.7	15.0	19.6	15.6	10.0	9.2	
oAGWO	7.7	5.4	1.5	11.4	10.4	11.9	15.7	4.9	
sAGWO	7.7	5.4	1.3	11.4	10.4	11.9	16.0	4.9	
oTAET	14.6	12.6	9.1	19.5	17.0	20.0	22.0	12.1	7.8
sTAET	14.6	12.6	10.6	19.5	17.0	20.0	22.1	12.2	7.8

Figure 2-6. Results of HSPF model verification of Chico Creek Main Stem for observed ("o" – solid bars) and simulated ("s" – striped bars) partitioning of annual SURO, IFWO, AGWO, and TAET by each land use class and impervious (IMPERV) surfaces.

2.1.3 Watershed Submodel Verification

We verified the watershed submodels by calculating the Nash–Sutcliff (NS) error statistic between observed and predicted data (NS = 1.0 means a perfect match), calculating the regression coefficient (R^2) between the predicted and observed data, and using professional judgment on final parameter selection. Overall, the verification results showed that model performance was GOOD-to-EXCEPTIONAL for most of the submodels (Table 2-3). Well-delineated watersheds like Chico, Clear, Barker, and Strawberry, which all had adequate data to support model deployment, performed exceptionally well and were capable of reproducing the partitioning of average annual precipitation for both the overall model as well as individual land uses (Figure 2-6). Other stream systems like Gorst, Springbrook, Blackjack, Anderson, and Karcher Creeks, and the stormwater systems for East Bremerton (Pine Rd., BST01) and Manchester (LMK038), were very good at matching the observed data and annual precipitation targets, largely due to the sufficient amount and quality of monitoring data available to support the calibration and verification process. Highly developed basins with limited data for calibration such as downtown Bremerton (Pacific Ave., BSTCSO16) and West Bremerton (Callow Ave., BST28) resulted in models that were less accurate; however, they provided results that were deemed acceptable for simulating watershed scale runoff. For example, BST28 tended to overpredict surface runoff by about 25% on an annual basis, yet the model faithfully reproduced the timing and relative intensity of storm event peaks and discharge volumes (Skahill and LaHatte, 2006).

Two of the models for stormwater flow within the Shipyard, PSNS015 and PSNS126, could be used to simulate individual storm events with FAIR accuracy, but due to very limited data and extreme tidal influences at the monitoring stations, the calibration record was not sufficient for simulating watershed-scale runoff. The flow monitoring data were not adequate to support model deployment for BST12, LMK122, LMK136, PSNS124, and POPOBLVD due to limited data, tidal influences, malfunctioning equipment, and/or problems with the geometry/layout of the monitoring site (Table 2-3) (TEC, 2004, 2005).

Supporting information for the HSPF modeling results, including reports documenting details of calibration and verification analysis, plots of verification results for all submodels, and model simulation files, is available on the distribution CD or via the internet (Table 1-1)

2.1.4 Watershed-Scale Hydrologic Simulation

The watershed-wide simulation for Sinclair and Dyes Inlets consisted of 17 landscape segments and 15 HSPF submodels (Figure 2-3, Table 2-4). The submodels were used to simulate watershed hydrology for 39 streams (open channel flows), 58 stormwater catchments areas (piped flows), and 44 shoreline drainage areas (overland flows) for a total of 138 basins draining into the inlets from the watershed. By assuming that the parameters obtained for the calibrated/verified systems were also applicable to the other watersheds within a given landscape segment, the calibrated/verified models were used to simulate flow for the other ungauged ("piggy-backed") systems within a landscape segment. Watershed scale simulations were conducted by driving the individual models with meteorological data for the desired simulation period from the subset of rain gauges assigned to each landscape segment (Skahill and LeHatte, 2007) to simulate 15-minute flow hydrographs for each of the subwatersheds within the study area. Predicted flows for the watershed are availabe on the distribution CD and via the internet (Table 1-1).

Table 2-3. Verification results for HSPF submodels, comparison between observed and predicted statistics for NS and R2 regression coefficients, and evaluation of model performance (Skahill and LaHatte, 2006).

Model	Basin	NS	R^2	Evaluation
ANDERSON	Anderson Creek	0.97	0.97	GOOD
BARKER	Barker Creek	0.99	0.95	EXCEPTIONAL
BJACK	Blackjack Creek	0.98	0.97	GOOD
BST01	Pine Rd.	0.95	0.96	GOOD
BST28	Callow Ave.	0.82	0.85	OK
BSTCSO16	Pacific Ave.	nr	nr	FAIR
CHICO	Chico Creek	0.94	0.95	EXCEPTIONAL
CLEAR	Clear Creek	0.99	0.99	EXCEPTIONAL
GORST	Gorst Creek	0.98	0.99	GOOD
KARCHER	Olney Creek	0.57	0.61	GOOD
LMK001	Silverdale Mall (W).	0.98	0.99	GOOD
LMK002	Bucklin Hill Rd.	0.99	0.98	GOOD
LMK038	Manchester Ave.	0.98	0.99	GOOD
SBC	Springbrook Cr.	0.97	0.98	GOOD
STRAW	Strawberry Cr.	0.99	0.99	EXCEPTIONAL

Not Used for Watershed Scale Simulation

Model	Basin	NS	R^2	Evaluation
PSNS015	Naval Sta McDonalds	nr	nr	FAIR
PSNS126	CIA CSO16	nr	nr	FAIR
LMK136	Annapolis Creek			NOT USEABLE
PSNS124	CIA Bld 438			NOT USEABLE
POPOBLVD	Port Orchard Blvd			NOT USEABLE

nr – not reported

2.1.5 Watershed Model Evaluation

We evaluated the watershed model by comparing the performance of the individual models in reproducing observed data during the verification exercise and rating their performance as EXCEPTIONAL, GOOD, OK, FAIR, or NOT USEABLE (Table 2-3). The rating was based on the NS and R^2 regression coefficients obtained between observed and predicted data and professional judgment (Skahill and LaHatte, 2006, 2007). The ratings were extended to the downstream and adjoining segments of the rated system within each landscape segment. For example, the CHICO model was calibrated and verified at the Chico Creek Main Stem gauging station located at Golf Club Hill Rd (DSN091) and about 2 kilometers upstream of the pour point at the mouth of stream (DSN087). Thus, the EXCEPTIONAL rating for CHICO was assigned, by extension, to the remainder of the stream. For the "piggy-backed" systems, it was assumed that the rating obtained for the calibrated/ verified system would also apply to the rest of the watersheds within that landscape segment. So, for CHICO, the adjoining watersheds at Erlands Point and along Chico Bay (DSNs 25, 97, 65, 95, and 68; see ENVVEST Spatial Viewer, Table 1-1) were also assumed to be exceptional "(Assumed) EXCEPTIONAL" with respect to representing landscape-scale runoff processes (Table 2-4). This assumes that the models deployed for the "piggy-backed" systems would perform at similar levels. However, no data are presently available to support or refute this claim. The rating for

the "piggy-backed" systems is probably optimistic and could more accurately be interpreted as the "best result available" for the ungauged systems.

Obviously, each watershed is unique and the ability to transfer the model parameters to other basins is not without uncertainty. However, the watersheds within each landscape segment are very similar with respect to geography, LULC, and meteorological forcing. The ability to deploy a wide range of submodels throughout the watershed greatly increases our confidence in the modeled results and is better than, for example, just applying the model developed for Chico Creek to the entire watershed. Another factor is that any errors or biases introduced by a particular submodel would only affect the predictions within that landscape segment. The model deployment was supported by a very diligent field monitoring program that tried to develop a distributed network of flow and rain monitoring stations in streams and stormwater basins (Figure 2-2). The calibration and verification process included as much information as possible about engineered conveyance systems and other factors that would affect runoff within the resource constraints available to support the project.

The models applied to the streams and stormwater systems were based on actual measurements of flows and care was taken to not "over-calibrate" any of the submodels such that the predictions would not be applicable to nearby basins. This was accomplished, in part, by the use of the PEST tool (see Section 2.1.1), which was very effective at determining local minima and avoiding parameter sets that would provide an acceptable fit to observed data but would not be stable for conditions that deviated from the calibration regime (Skahill and Dogherty, 2006). By focusing the calibration on the landscape-scale processes (e.g., SURO, IFWO, AGWO, TAET, I-SURO, and I-TAET), some of the accuracy of meeting the "hard data" (stage-discharge relationships) was sacrificed in favor of models that were more widely applicable to the watershed as whole.

The ability to explicitly model flows at individual pour points is also an advantage for identifying and implementing source controls and Best Management Practices (BMPs) because of the direct linkage between the spatial distribution of the discharges and the upstream drainage areas. For example, if a particular nearshore area, such as Northern Dyes Inlet, is identified as problematic, the pour points contributing to the problem can be identified and assessed for pollution identification and control (PIC) projects.

Based on the evaluation results, we were very confident that the watershed model developed for Sinclair and Dyes Inlets could effectively simulate surface water flows from streams. We were more uncertain about the predictions for runoff from stormwater outfalls and shoreline areas than from streams; however, the stream systems had much higher flows than the other systems, and would, therefore, account for a higher fraction of the total load into the estuary. Because the streams, shoreline areas, and stormwater outfalls were included as spatially explicit pour points within the model, it was possible to evaluate their relative contribution to total loading from the watershed (see Figure 3-10 and Figure 3-11). We concluded that the watershed submodels could simulate the watershed-scale hydrology of the Sinclair and Dyes Inlets watershed with GOOD-to-EXCEPTIONAL accuracy for streams and FAIR-to-GOOD accuracy for stormwater basins.

Table 2-4. Watershed pour points simulated by HSPF submodels of landscape segments and the model's performance in predicting stream, stormwater, and shoreline runoff into Sinclair and Dyes Inlets.

Model	DSN	Type	Name (Pour Point)	Model Performance
ANDERSON	57	Stream	Anderson Creek	**GOOD**
ANDERSON	28	Shoreline	Elandan (Gorst South)	(Assumed) GOOD
ANDERSON	30	Shoreline	Ross Point	(Assumed) GOOD
BARKER	58	Stream	Barker Creek	**EXCEPTIONAL**
BARKER	92	Stream	Mosher Creek	(Assumed) EXCEPTIONAL
BARKER	103	Shoreline	Paxford	(Assumed) EXCEPTIONAL
BARKER	73	Stream	Pharman Creek	(Assumed) EXCEPTIONAL
BARKER	72	Stream	Stampede Creek	(Assumed) EXCEPTIONAL
BARKER	102	Shoreline	Stampede	(Assumed) EXCEPTIONAL
BARKER	100	Shoreline	Tracyton Boulevard	(Assumed) EXCEPTIONAL
BARKER	101	Shoreline	Windy Point	(Assumed) EXCEPTIONAL
BJACK	187	Stream	Annapolis Creek	(Assumed) EXCEPTIONAL
BJACK	32	Stormwater	Bay Street	(Assumed) EXCEPTIONAL
BJACK	202	Stormwater	Bethel Ave	(Assumed) EXCEPTIONAL
BJACK	193	Stream	Blackjack Creek	**EXCEPTIONAL**
BJACK	186	Stormwater	PO Retsil	(Assumed) EXCEPTIONAL
BJACK	188	Stormwater	Perry Avenue	(Assumed) EXCEPTIONAL
BJACK	189	Stormwater	Cline Avenue	(Assumed) EXCEPTIONAL
BJACK	185	Stormwater	Farragut Avenue	(Assumed) EXCEPTIONAL
BJACK	183	Stormwater	Port Orchard Boulevard	(Assumed) EXCEPTIONAL
BJACK	93	Stream	Ross Creek	(Assumed) EXCEPTIONAL
BJACK	31	Stormwater	Wilkens	(Assumed) EXCEPTIONAL
BST01	19	Stormwater	Boat Shed	(Assumed) GOOD
BST01	11	Stormwater	Campbell Way	(Assumed) GOOD
BST01	9	Stormwater	Stephenson	(Assumed) GOOD
BST01	6	Stream	Dee Creek	(Assumed) GOOD
BST01	10	Stormwater	East Park	(Assumed) GOOD
BST01	13	Shoreline	East Park Shoreline	(Assumed) GOOD
BST01	8	Stormwater	Lions Park	**GOOD**
BST01	17	Stormwater	Marlowe Avenue	(Assumed) GOOD
BST01	18	Shoreline	Parkside	(Assumed) GOOD
BST01	7	Stormwater	Pine Road	(Assumed) GOOD
BST01	12	Shoreline	Reid	(Assumed) GOOD
BST01	199	Shoreline	Tracyton Beach	(Assumed) GOOD
BST01	195	Stormwater	Tracyton (Boat Ramp)	(Assumed) GOOD
BST01	16	Stormwater	Trenton	(Assumed) GOOD
BST28	142	Stormwater	Anderson Cove	(Assumed) OK
BST28	158	Stormwater	Charleston Parking Lot	**OK**
BST28	214	Shoreline	Gorst North	(Assumed) OK
BST28	154	Stormwater	Loxie Eagans	(Assumed) OK
BST28	153	Stormwater	National Ave	(Assumed) OK
BST28	215	Stormwater	Navy City Metals	(Assumed) OK
BST28	151	Stormwater	Oyster Bay	(Assumed) OK
BST28	143	Stormwater	Phinney Bay	(Assumed) OK
BST28	141	Stormwater	Snyder Avenue	(Assumed) OK
BST28	140	Stormwater	Stevens Drive	(Assumed) OK
BST28	152	Stream	Wright Creek	(Assumed) OK

Table 2-4. (continued).

Model	DSN	Type	Name (Pour Point)	Model Performance
BSTCSO16	146	Stormwater	Chester Avenue	(Assumed) FAIR
BSTCSO16	162	Stormwater	Evergreen Park	(Assumed) FAIR
BSTCSO16	148	Stormwater	Ohio Avenue	(Assumed) FAIR
BSTCSO16	165	Stormwater	Pacific Avenue	(Assumed) FAIR
BSTCSO16	223	Stormwater	Park Ave/17th	(Assumed) FAIR
BSTCSO16	177	Stormwater	PSNS126/CSO16 (Pier #8)	**FAIR**
BSTCSO16	169	Stormwater	PSNS (Bldg 455)	(Assumed) FAIR
BSTCSO16	172	Stormwater	PSNS (Bldg 457)	(Assumed) FAIR
BSTCSO16	170	Stormwater	PSNS (Bldg 480)	(Assumed) FAIR
BSTCSO16	175	Stormwater	PSNS (Drydock #1)	(Assumed) FAIR
BSTCSO16	176	Stormwater	PSNS (Drydock #2)	(Assumed) FAIR
BSTCSO16	171	Stormwater	PSNS (Drydock #5)	(Assumed) FAIR
BSTCSO16	168	Stormwater	PSNS (FISC)	(Assumed) FAIR
BSTCSO16	166	Stormwater	PSNS (Inactive Ships)	(Assumed) FAIR
BSTCSO16	173	Stormwater	PSNS (N Street)	(Assumed) FAIR
BSTCSO16	167	Stormwater	PSNS (NavSta-McDonalds)	(Assumed) FAIR
BSTCSO16	174	Stormwater	PSNS (Pier #5)	(Assumed) FAIR
BSTCSO16	178	Stormwater	PSNS Main Gate	(Assumed) FAIR
BSTCSO16	144	Stormwater	Thompson Avenue	(Assumed) FAIR
BSTCSO16	161	Stormwater	High Avenue	(Assumed) FAIR
BSTCSO16	150	Stormwater	Washington Avenue	(Assumed) FAIR
BSTCSO16	147	Shoreline	WB Narrows Park Ave	(Assumed) FAIR
CHICO	95	Shoreline	Chico Bay North	(Assumed) EXCEPTIONAL
CHICO	97	Shoreline	Chico Bay South	(Assumed) EXCEPTIONAL
CHICO	87	Stream	Lower Chico Cr.	**EXCEPTIONAL**
CHICO	65	Stream	Erlands Creek	(Assumed) EXCEPTIONAL
CHICO	25	Shoreline	Erlands Point	(Assumed) EXCEPTIONAL
CHICO	71	Stormwater	Jackson Park Creek	(Assumed) EXCEPTIONAL
CHICO	201	Shoreline	Madrona Point	(Assumed) EXCEPTIONAL
CHICO	22	Shoreline	NAD Park	(Assumed) EXCEPTIONAL
CHICO	149	Stream	Ostrich Bay Creek	(Assumed) EXCEPTIONAL
CHICO	145	Shoreline	Oyster Bay West Shore	(Assumed) EXCEPTIONAL
CHICO	26	Shoreline	Rocky Point	(Assumed) EXCEPTIONAL
CHICO	139	Shoreline	W. Phinney Bay	(Assumed) EXCEPTIONAL
CLEAR	136	Stormwater	Clear Creek	(Assumed) EXCEPTIONAL
CLEAR	127	Stream	Clear Creek (Main Flow)	**EXCEPTIONAL**
GORST	55	Stream	Gorst Creek	**GOOD**
GORST	27	Stormwater	Gorst Subaru	(Assumed) GOOD
GORST	29	Stream	Spring Creek	(Assumed) GOOD
KARCHER	33	Shoreline	Annapolis Pt.	(Assumed) GOOD
KARCHER	37	Shoreline	Beach Drive	(Assumed) GOOD
KARCHER	38	Shoreline	Hillcrest	(Assumed) GOOD
KARCHER	36	Shoreline	Lindstrom	(Assumed) GOOD
KARCHER	64	Stream	Olney Creek	**GOOD**
KARCHER	34	Shoreline	Olney Shoreline	(Assumed) GOOD
KARCHER	35	Stream	Retsil	(Assumed) GOOD
KARCHER	80	Stream	Rich Cove Creek	(Assumed) GOOD
KARCHER	76	Stream	Sacco Creek	(Assumed) GOOD
KARCHER	77	Stream	Sullivan Creek	(Assumed) GOOD
KARCHER	39	Shoreline	Waterman Point	(Assumed) GOOD
KARCHER	79	Stream	Waterman Creek	(Assumed) GOOD
LMK001	217	Stormwater	Silverdale Mall (West)	**GOOD**
LMK002	104	Stormwater	Bucklin Hill	(Assumed) GOOD
LMK002	216	Stormwater	Silverdale Mall (East)	**GOOD**
LMK038	81	Stream	Beaver Creek Lower	(Assumed) GOOD
LMK038	182	Stormwater	Manchester Fuel Depot	(Assumed) GOOD
LMK038	196	Stormwater	Manchester Upland	(Assumed) GOOD
LMK038	46	Shoreline	Manchester Point	(Assumed) GOOD

Table 2-4.,(continued).

Model	DSN	Type	Name (Pour Point)	Model Performance
SBC	203	Shoreline	Battle Point (BI)	(Assumed) GOOD
SBC	41	Shoreline	Crystal Springs (BI)	(Assumed) GOOD
SBC	45	Stormwater	Fort Ward (BI)	(Assumed) GOOD
SBC	206	Stream	Foster Creek	(Assumed) GOOD
SBC	83	Stream	Gazzam Creek	(Assumed) GOOD
SBC	40	Shoreline	Hansen (BI)	(Assumed) GOOD
SBC	74	Stream	Illahee Creek	(Assumed) GOOD
SBC	21	Shoreline	Illahee North	(Assumed) GOOD
SBC	23	Shoreline	Illahee South (MESO-NW)	(Assumed) GOOD
SBC	24	Shoreline	Illahee State Park	(Assumed) GOOD
SBC	205	Stream	Issei Creek	(Assumed) GOOD
SBC	208	Stream	West Fork Issei Creek	(Assumed) GOOD
SBC	82	Stream	Linquist Creek	(Assumed) GOOD
SBC	84	Stormwater	BI-Lynwood Center	(Assumed) GOOD
SBC	86	Stream	Lytle Creek	(Assumed) GOOD
SBC	207	Stream	North Fletcher Bay Creek	(Assumed) GOOD
SBC	44	Shoreline	Pleasant Beach (BI)	(Assumed) GOOD
SBC	42	Shoreline	Point White (BI)	(Assumed) GOOD
SBC	43	Stream	Schel-Chelb Creek (BI)	(Assumed) GOOD
SBC	85	Stream	S. Fork Schel-Chelb Cr (BI)	(Assumed) GOOD
SBC	204	Shoreline	South Fletcher (BI)	(Assumed) GOOD
SBC	210	Stream	Springbrook Creek	**GOOD**
SBC	75	Stream	State Park Creek	(Assumed) GOOD
STRAW	99	Stormwater	Bayshore	(Assumed) EXCEPTIONAL
STRAW	137	Shoreline	Cedar Terrace	(Assumed) EXCEPTIONAL
STRAW	96	Shoreline	Chico Way	(Assumed) EXCEPTIONAL
STRAW	68	Stream	Crystal Creek	(Assumed) EXCEPTIONAL
STRAW	67	Stream	Koch Creek	(Assumed) EXCEPTIONAL
STRAW	98	Shoreline	Old Silverdale	(Assumed) EXCEPTIONAL
STRAW	94	Stream	Strawberry Creek	**EXCEPTIONAL**
STRAW	66	Stream	Woods Creek	(Assumed) EXCEPTIONAL

2.2 Modeling FC Concentrations in Streams and Stormwater Outfalls

2.2.1 Overview

We used empirical relationships between FC concentrations measured in streams and outfalls and upstream LULC to develop a statistical model for predicting FC concentrations for all streams, shoreline areas, and stormwater discharges in the study area (May et al., 2005). Landscape features were clustered into statistically similar groups, and then the sample distribution attributes of each cluster were used to “bound” (interval estimation) the FC concentration. The geometric mean concentration for each stream and shoreline watershed was estimated by regressing the mean FC concentration against the discriminant scores obtained from the cluster analysis. Stormwater outfalls were divided into statistically similar groups based on LULC, and the geometric mean concentration and prediction bounds were determined by available data. A summary of the analysis is provided below; the details of the analysis are reported in Section 8 of May et al. (2005).

2.2.1.1 Calculating FC Loading Concentrations for Streams

Land use and land cover (LULC) data in the Sinclair-Dyes Inlets watershed were analyzed using the 1999 Landsat-7 Thematic Mapper (TM) remote-sensing satellite data within a GIS at 30-meter

pixel resolution (CTC, 2001). The cluster analysis was performed using nine LULC variables selected based on their variability, correlation with FC concentration characteristics, and a minimum of redundancy (Table 2-5). These variables represented the natural landscape, human development, and riparian conditions. The percentage total impervious surface area (%TIA) was not used because it is a function of other LULC variables and requires assumptions that could change between watersheds, while the raw variables are not dependent on such assumptions.

Hierarchical tree clustering was used to determine the number of clusters, followed by k-means clustering on standardized data to determine the members of each cluster. The k-means clustering analysis was conducted on standardized data (value-mean/standard deviation) so that all variables would be centered at zero and have a standard deviation of 1. Five clusters indicated 20% of the maximum linkage distance. The value of 20% was chosen to maximize the number of clusters that would be significantly different (May et al., 2005).

Table 2-5. LULC variables, discriminate score coefficients (COEF), and the amount of variation explained for separation between the five clusters (May et al., 2005).

Variable	Abbrev.	COEF1	COEF2	COEF3	COEF4
% Coniferous Forest	%CF	1.3674	1.1719	-0.6865	-0.6606
% Grass/Turf (Herbaceous Range Land)	%HL	0.0443	-1.0336	0.6069	-0.5853
% Rural (LD Residential)	%LD	0.7068	-1.1404	-1.0382	-0.3234
% Suburban (MD Residential)	%MD	0.0376	0.4704	0.1029	-0.7554
% Urban (HD Residential)	%HD	-1.3615	-0.4389	0.0884	0.1913
% Commercial/Industrial	%CI	-0.6886	0.0670	-0.8119	-1.5281
Road Density (km/km^2)	RD	-0.0559	-0.0581	-0.5146	-0.1886
Stream-Crossings/Stream-Length (#/km)	SC/SL	-0.6502	-0.2372	0.1150	1.6075
% Coniferous Forest-100 m Buffer	%CFB100	0.0423	-0.1286	-0.4696	0.8001
Eigen value		14.7496	2.8928	0.6871	0.3046
Cumulative Variation Explained		79%	95%	98%	100%

The cluster analysis of stream watersheds resulted in five well-separated clusters with significantly different variables between clusters. The clusters were described by their level of human development from least to greatest using a selection of the LULC variables measured as a percent (Figure 2-7A). Watersheds in Cluster 4 had the greatest level of development (greatest development) with an average of 26% urban (high-density residential) and 25% commercial–industrial development. Watersheds in Cluster 5 had slightly less development (medium–low density development) with an average of 14% urban and 19% commercial–industrial development. Watersheds in Clusters 2 (rural low development) and 3 (grass/turf/pasture) had similar amounts of urban and commercial–industrial development (9%), but Cluster 2 had more rural (19%) and less suburban (5%) development than Cluster 3, which only had 2% rural and but 9% suburban development. Watersheds in Cluster 1 (Coniferous Forest) had the most coniferous forest cover and the least level of development with less than 5% urban, commercial, and suburban development and only 6% rural development.

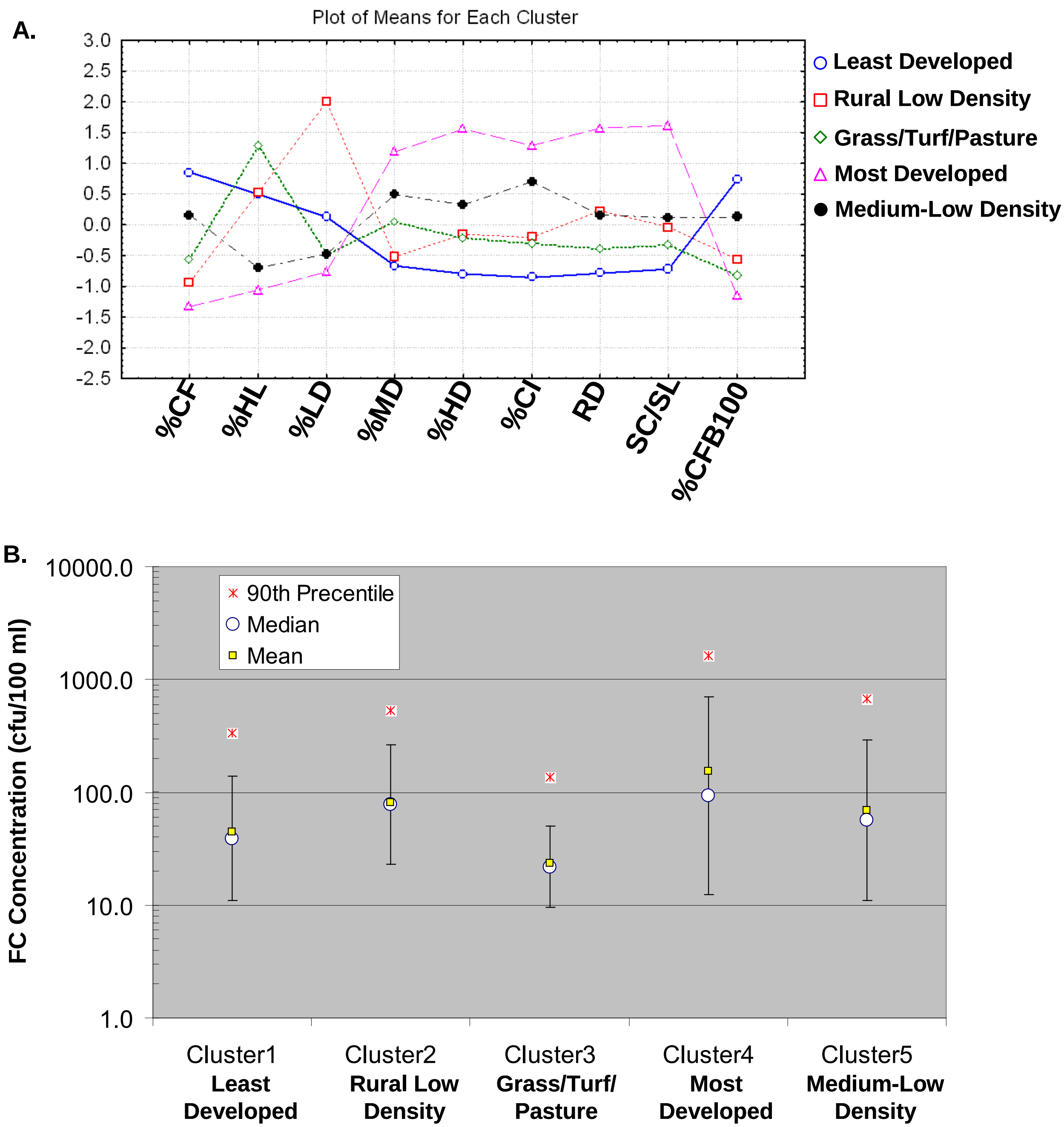


Figure 2-7. Results of cluster analysis for streams showing the standardized cluster mean for each cluster and variable in the model (A) and median (circle ±25th and 75th percentiles), mean (square), and 90th percentile (*) confidence intervals for fecal coliform concentrations by cluster (B). See Table 2-5 for definition of LULC variables.

The variability in FC concentrations within a cluster did not allow a complete separation of clusters. Only Cluster1 (least developed) and Cluster4 (most developed) had significantly different mean FC concentrations ($p < 0.01$) (Figure 2-7B). Assuming cluster membership was correct, discriminant analysis of the landscape clusters was performed to provide a set of explanatory

regression variables (discriminant scores) to estimate FC concentrations. Regression analysis was used to estimate the geometric mean FC concentration, and the sample distribution attributes of each cluster were used to bound it. Discriminant analysis of the landscape clusters provided an alternate set of explanatory regression variables (discriminant scores) to estimate FC concentrations (Hand, 1981). Discriminant analysis is a technique of deriving classification rules from samples that are already classified into groups. The resulting discriminant scores for each landscape are linear combinations of the standardized LULC variables that were used in the cluster analysis. This method provides a single estimate of the geometric mean for each stream.

The first two discriminant scores explained 95% of the variability among the landscape clusters (Table 2-5). However, when the FC concentration (the dependent variable) was regressed against the first two discriminant scores, only Score 1 was significant ($p < 0.001$) (Table 2-6).

Table 2-6. Regression summary for FC concentrations as a function of the first two discriminant scores (*Score1* and *Score2*). From May et al., 2005.

Variable	Coefficient	Standard Error of the Coefficient	t-statistic (df = 35)	p-value
Intercept	74.6302	9.918171	7.52460	p < 0.000001
Score1	-12.7941	2.598404	-4.92382	0.000020
Score2	-5.6516	5.109494	-1.10610	0.276230
Source of Variation	**Sums of Squares**	**Degrees of Freedom**	**F-statistic**	**p-level**
Regression	93194.8	2	12.56184	0.000077
Residual	129830.5	35		
Total	223025.4			

The regression was significant ($p < 0.001$) and had an R^2 value of 0.38. The magnitudes of the standardized residuals were all less than three and had no particular pattern except that the variance was larger for the smaller scores (May et al., 2005). Therefore, the geometric mean (Geomean) FC concentration for stream watersheds was predicted using the first discriminant score:

$$\text{Geomean FC [cfu/100 ml]} = 74.63 - 12.794(\mathit{Score1}), \qquad [1]$$

where

Score1 is the first discriminant score for the watershed subbasin of interest

Once a cluster assignment was determined, the bounds for the FC concentrations were defined as the 25th percentile of the cluster's 25th percentile of the observations for streams within the cluster and the 75th percentile of the cluster's 75th percentile of the observations for streams within the cluster (Table 2-7). For modeling purposes, when the predicted geometric mean was greater than the cluster within stream 75th percentile, the overall 75th percentile (using all geometric means for streams within a given cluster) was used to estimate the geometric mean. Likewise, when the predicted geometric mean was less than the cluster within stream 25th percentile, the overall 25th percentile of the geometric means was used to estimate the geometric mean (May et al., 2005).

Table 2-7. The distribution of FC concentrations for the 25th, 50th (geomean), 75th, and 90th percentiles used to estimate FC concentration boundaries for each cluster (May et al., 2005).

	FC Concentration cfu/100 ml				
Cluster	25th	Mean	Median	75th	90th
Cluster 1	11.0	44.7	39.0	138.0	337.0
Cluster 2	23.0	80.3	77.8	263.0	532.0
Cluster 3	9.5	23.7	21.8	50.0	136.0
Cluster 4	12.3	152.8	93.1	705.0	1630.0
Cluster 5	11.1	68.5	57.1	294.0	680.0

For the final (2005) loading-estimation data analysis, all watersheds were reassigned a cluster based on the results of the 2005 data analysis. It was assumed that the number of clusters, the variables used to cluster landscape characteristics, the regression of mean FC as a function of discriminant scores, and the cluster FC characteristics were the same as the 2004 analysis. The only difference between the 2004 and 2005 data was that a small number of subbasins were reclassified as stormwater or streams, and some were subdivided and redelineated based on more accurate drainage characterization. These changes did not significantly change the FC statistics.

The FC geomean concentrations were also estimated for shoreline areas that have direct runoff into the marine receiving waters by assuming that runoff from these areas would be similar to the streams with similar LULC characteristics. The LULC information from the shoreline watersheds were used to assign the watersheds to the appropriate cluster and the geomean concentration was calculated using EQU [1]. Because sampling direct-runoff from shoreline areas is very difficult, the FC concentrations for these areas were estimated using the data from stream sub-basins with comparable land-use patterns. Treating shoreline direct runoff areas the same as streams may underestimate the actual FC concentrations for these direct runoff areas, especially for heavily developed shoreline areas, but it is a better comparison than treating them as stormwater because, for the most part, they lack an engineered collection and conveyance system. In general, they are more "stream-like" in source type and runoff behavior (May et al., 2005).

2.2.1.2 Calculating Loading Concentrations for Stormwater Outfalls

We also used emprical data to estimate the FC loading concentrations from stormwater outfalls. The watershed monitoring program included a subset of stormwater outfalls that drained industrial, urban, suburban, and rural areas. During the 2002–2003 storm season, data on FC in the outfalls were collected from about seven storm events[5] (see Figure 7-30 in May et al., 2005). These results were used to infer FC concentrations for other unmeasured outfalls and engineered drainage areas (May et al., 2005). The FC concentrations from outfalls were highly variable; the coefficient of variation (CV) averaged 150% (May et al., 2005). The outfalls fell into three developmental groups: urban with commercial–industrial development (urban), rural development (rural), and light suburban development (suburban). The cluster and regression model developed for the streams was not directly applicable to the stormwater systems. The landscape characteristics did not correlate well with the outfall FC concentrations, probably because most of the outfalls only flowed during storm events and there was a relatively small sample size (May et al., 2005). Instead, descriptive statistics associated with the level of development were used to provide a boundary or interval estimate on the FC concentration in the stormwater systems. Concentration intervals were based on the geometric

[5] Not every outfall was sampled for every storm event.

mean (geomean) of each group bounded by the 25th and 75th percentile of the group's distribution (Table 2-8, Figure 2-8). The intervals allowed an estimate of the variability in concentration to be included in the loading analysis.

Table 2-8. Descriptive statistics for outfall FC concentrations used to estimate FC concentrations for outfalls in the Sinclair and Dyes Inlets watershed (May et al., 2005).

			cfu/100 ml					
						Precentile		
Group	Development	n	Mean	Min	Max	25th	Median	75th
Group1	Urban\Industrial	26	947	10	7602	210	513	1255
Group2	Rural	3	321	158	459	158	269	459
Group3	Suburban	4	140	61	310	62	128	263
All Outfalls	All	33	792	10	7602	573	1305	2970

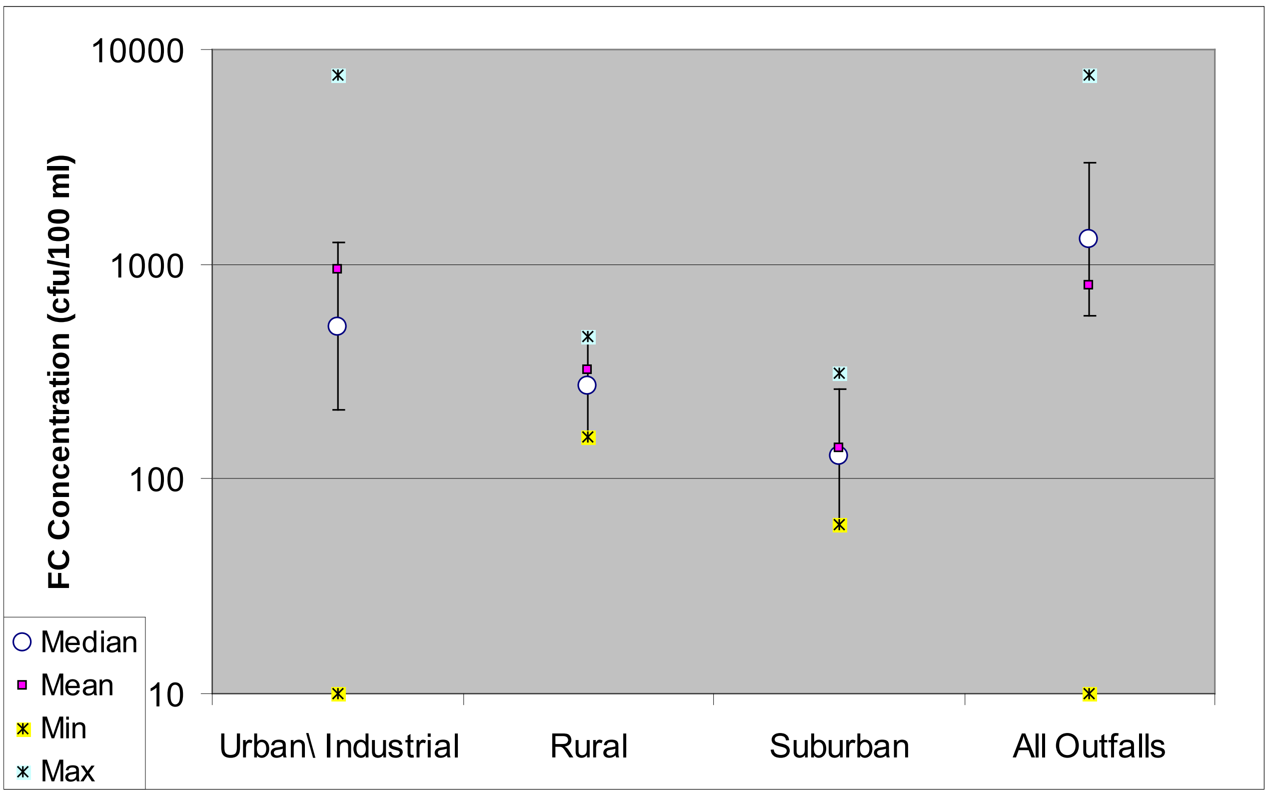


Figure 2-8. Predicted FC concentrations for outfall types showing the median (circle ±25th and 75th percentiles), mean (square), minimum (*), and maximum (*).

2.2.2 Evaluation of FC Concentration Predictions

We assessed the empirical relationships between FC concentrations and upstream LULC to develop a statistical model for predicting FC concentrations in streams and stormwater outfalls throughout the watershed (May et al., 2005). This assessment was accomplished by collecting data from a representative set of streams and stormwater drainage areas that spanned the full range of

LULC characteristics found within the watershed and then applying the statistical relationships from the monitored systems to the unmonitored systems.

Five statistical methods were evaluated (May et al., 2005):

1. Regression analysis using time of year and flow
2. Application of distribution statistics
3. Stepwise regression using landscape characteristics
4. Cluster analysis using landscape characteristics
5. Regression with cluster scores

The best approach was cluster analysis using landscape characteristics along with regression with cluster scores and FC concentration (i.e., "k-cluster regression," Methods 4 and 5) (May et al., 2005). This approach was selected because it achieved the lowest residual error between observed and predicted data, extrapolation to unmeasured systems was not required, and concentration intervals were defined to represent uncertainty about the estimate. There was no need for extrapolation to unmeasured watersheds because the LULC variables needed to assign clusters and estimate FC loading concentrations were readily available for all watersheds. By estimating the 25th and 75th percentile of the cluster's distribution, the method provided a means to estimate the variability in FC loading concentrations (May et al., 2005). Although the k-cluster regression was not applicable to the stormwater outfalls, a similar clustering approach was used for the outfalls based on professional judgment and available data.

The uncertainty and confidence in estimating the FC loading concentration for the watersheds in Sinclair and Dyes Inlets was evaluated by comparing the overall predictions to data collected from January 2000–September 2003 (2000–2003) and October 2002–September 2003 (WY2003). These periods are appropriate because they represent the "present conditions" in the watershed for which the models were developed and are the basis for simulating load and waste load allocations for the bacterial TMDL. During the statistical model development, flow data from the watershed model for three stream watersheds (Blackjack Creek [BJACK], Gorst Creek [GORST], and Strawberry Creek [STRAW]) were not yet available. Consequently, results from the k-cluster regression analysis developed from the other watersheds were used to predict FC loading concentrations for BJACK, GORST, and STRAW to see how well the predictions compared to observed data (Figure 2-9).

The BJACK and GORST streams were both assigned to Cluster1, and STRAW was assigned to Cluster5. The discriminate scores from the cluster analysis were used to estimate the geomean using EQU [1], and the resulting geomean was used to calculate the predicted load for each stream:

$$\text{Load [counts/sec]} = \text{FC [cfu/100 ml]} \times \text{Flow [cfs]}, \qquad [2]$$

where

FC = fecal coliform concentration (geomean)

Flow = modeled stream flow in cubic feet per second.

The resulting "predicted load" was compared to the "observed load" using the geometric mean calculated from the observed data (Figure 2-9). The residual mean squares were calculated in log space as the difference between the observed FC loading calculated for each individual data point (circles in Figure 2-9) and the loads calculated with the observed and predicted geometric mean FC concentration (Table 2-9).

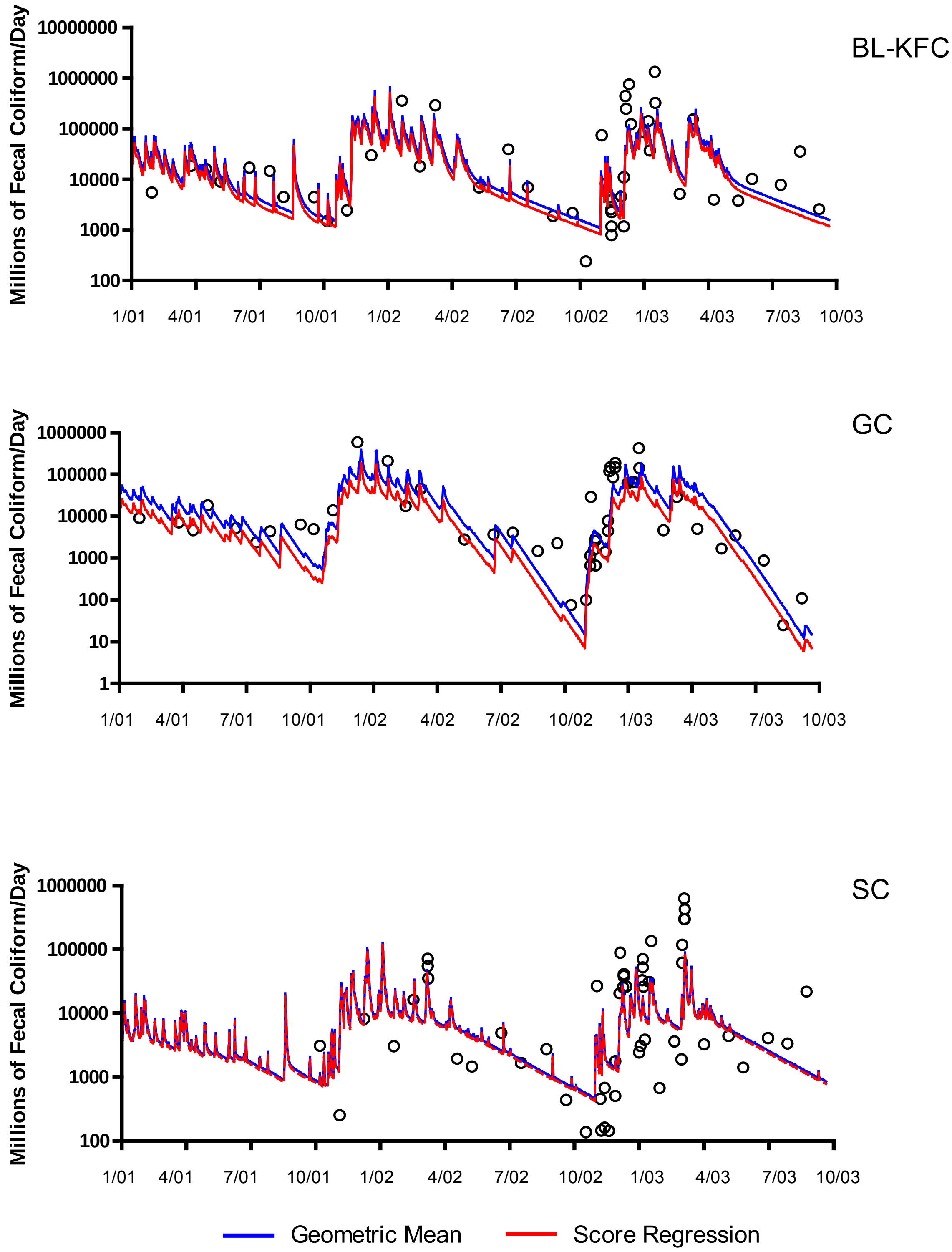


Figure 2-9. Observed fecal loads (circles) and simulated loadings using the geometric mean from the observed data (blue lines) and the predicted mean from the k-cluster regression (red lines) for Blackjack (BL-KFC), Gorst (GC), and Strawberry (SC) Creeks (from May et al., 2005).

Table 2-9. Stream, cluster, discriminant score, observed and predicted geometric mean, and resulting residual mean squares calculated based on the observed and predicted load for each stream.

			Geometric Mean cfu/100 ml		Residual Error	
Stream	Cluster	Score 1	Observed	Predicted	Observed	Predicted
BJACK	1	2.00	65.0	49.0	0.287	0.312
GORST	1	3.35	67.0	31.8	0.331	0.504
STRAW	5	-0.60	90.0	82.4	0.368	0.372

The results of the comparison showed excellent agreement between the observed and predicted loads, especially for Strawberry Creek (Figure 2-9), and the residuals were not greatly different between estimates based on the observed or the predicted geometric mean (Table 2-9). While there was some disagreement between the individual points and the simulated time series, the simulated loads tracked the observed points quite well, particularly in capturing peak events associated with storms and wet season flows. The mismatch between observed points and the simulated time series during low flow conditions (dry periods) is not troubling because the total FC loading during these periods is greatly reduced. It is even more impressive to note that the FC loading hydrograph based on the regression score is almost virtually the same as the loading hydrograph obtained from the observed FC data, which means that FC loads can be estimated with some confidence even for watersheds where no FC data are available. Additionally, this is very effective for estimating loads from systems that are data limited or skewed because the existing FC data are not representative of the full range of weather conditions (dry and wet seasons as well as storm events). As can be seen by EQU [2], the load is controlled by the stream flow, which can vary by 3 to 5 orders of magnitude for some systems (Skahill and LaHatte, 2007), while the FC concentration typically varies by 1 to 2 orders of magnitude (May et al., 2005). Therefore, the success of applying the k-cluster regression method for estimating loads is greatly dependent on the watershed model's capacity to simulate watershed-scale processes at the individual pour points (see Section 2.1).

The k-cluster regression was based on all the available data within the watershed, including stream mouths, upstream segments, and tributary streams. The purpose of the analysis was to estimate the concentration load at the mouths of streams or pour points (Figure 2-10). Since the data from the upstream segments and tributary streams may or may not be reflective of concentrations at the mouths of streams, the predicted geometric mean FC concentrations (blue regression line with 90% prediction interval) were compared to the observed geometric mean at mouths of streams for all data from 2001–2003 and WY2003 as a function of cluster score (Score1) obtained from upstream LULC (Figure 2-10, Table 2-10). In general, the regression tracked the observed FC geometric mean at the stream mouths quite well. The regression showed a definite trend of increasing FC concentrations with decreasing discriminant scores, and most of the data fell within or near to the 95% prediction interval of the regression. However, there were notable exceptions. The regression tended to underestimate the FC concentrations observed at the mouths of Dee (DEE), Olney (OC), Annapolis (ANNP), and Ostrich Bay (OB01) Creeks; overestimate the FC concentration for Pharman (PA01) and Mosher (MS01) Creeks; and underestimate FC concentrations for Springbrook Creek (BISBC) at the other end of the spectrum (Figure 2-10, Table 2-10). More importantly, the observed concentrations for larger streams with high flow volumes like Chico, Clear, Blackjack, Strawberry, and Baker all fell within the 95% prediction interval of the regression (Figure 2-10, Table 2-10).

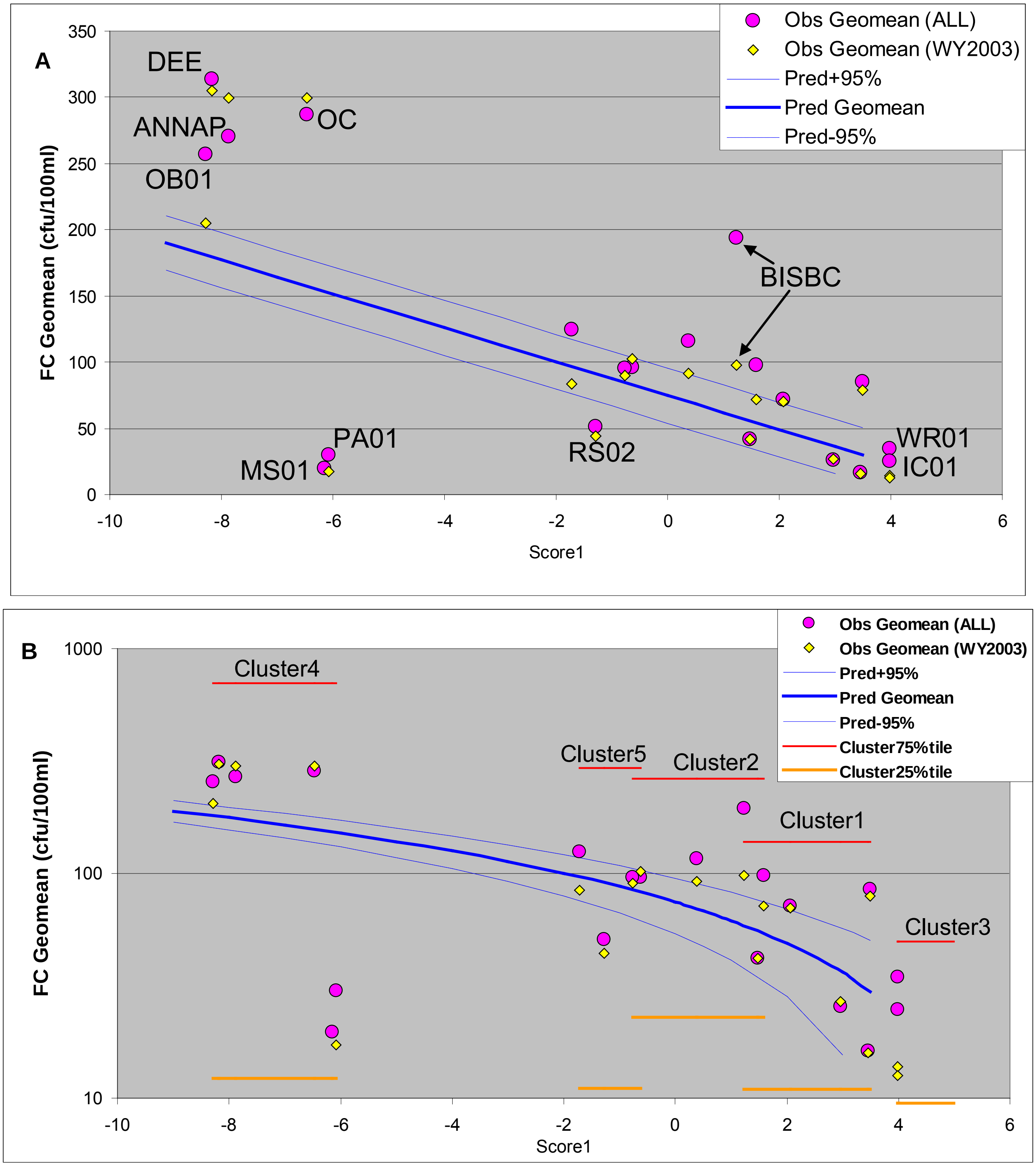


Figure 2-10. Comparison of predicted geometric mean FC concentrations (blue regression line with 90% prediction interval) to observed geometric mean at mouths of streams for all data from 2001-2003 (ALL-magenta circles) and WY2003 (yellow diamonds) as a function of cluster score (Score1) obtained from upstream LULC (A). Same data with 25th and 75th percentile bounds of each cluster on a log scale (B).

The observed data could depart from the regression line for many reasons. The high concentrations observed for DEE, OC, ANNAP, and OB01 relative to what was predicted from the regression score could be due to a variety of factors. Each of these streams has a long history of bacteria pollution problems (KCHD, 2002, 2004, 2005), and there may be other sources of FC, including failing septic systems, leaking sewer lines, and inputs from wildlife and water fowl that were not included in the FC statistical model.

The overprediction for Pharman and Mosher Creeks could be because these smaller streams in East Bremerton, which are located in well-defined canyons, are not as greatly influenced by the surrounding LULC as other basins within the watershed. The same may be true for Ross Creek (RS02) in Port Orchard, although to a lesser extent. The data for BISBC were very limited (n = 19 for all data[6] and n = 4 for WY2003). The BISBC station was located at the New Brooklyn Rd. culvert and was about 640 meters from the head of Fletcher Bay. The station is located in a relatively undeveloped area, but there may be inputs from unknown sources such as failing septic systems or wildlife and water fowl that were not included in the model. Despite these uncertainties and confounding factors, all the observed geometric means for the stream mouths fell within each cluster's 25th to 75th percentile interval (Figure 2-10B).

Note that the regression scores for Wright (WR01) and Illahee Creeks (IC01) fell outside of the upper bound for Cluster 3 of 50 cfu/100 ml, so they were set to the cluster median of 23.7 cfu/100 ml (see Table 2-7), which agreed well with the observed data (Figure 2-10, Table 2-10).

The prediction intervals obtained for the stormwater systems resulted in a static value applied to all outfalls, which fell short of capturing the between and within variation observed in the outfall data. For example, all the urban–industrial outfalls were set to the same value, but the observed data were widely variable (Figure 2-11). Additionally, the upper bound of the prediction interval (75th Percentile) for all groups tended to underestimate the observed 75th percentile for most of the outfalls (Table 2-11), suggesting that higher settings would be required if a simulation of the "worst case" situation for stormwater inputs was desired. On the other hand, the method was very practical, and it could be applied to unmeasured stormwater systems without extrapolation, and by providing a bounded estimate of the geometric mean concentration, the approach could be very effective in simulating the "central tendency" of the FC levels in stormwater sources. Since the FC concentrations in stormwater systems were so variable and difficult to predict, an alternative approach would be to introduce stochastic processes into the modeling that would randomly impose extreme variations into the predictions of the FC loading concentration to capture the variations observed in the real world (i.e., modeling the outfalls as nonlinear dynamical or chaotic systems). However, these types of approaches were outside the scope of the present work.

[6] All data for BISBC were collected from 7 November 2002–19 November 2004.

Table 2-10. The predicted and observed geometric mean (Geomean) and cluster confidence intervals for stream mouths (pour points).

					cfu/100 ml				
					Predicted			**Obs. Geomean**	
DSN	Basin	Station	Cluster	Factor Score1	25th %tile	Geo - mean	75th %tile	**2001-2003**	**WY 2003**
136	Clear Cr.	CC01	5	-1.717	11.1	96.6	294	124.3	83.9
93	Ross Cr.	ROSS	5	-1.282	11.1	91	294	51.0	44.0
94	Strawberry Cr.	SC	5	-0.628	11.1	82.7	294	96.5	102.2
187	Annapolis Cr.	ANNAP	4	-8.288	12.3	180.7	705	257.0	205.1
6	Dee Cr.	DEE	4	-8.175	12.3	179.2	705	313.4	305.3
149	Ostrich Bay Cr.	OB01	4	-7.874	12.3	175.4	705	270.1	299.2
64	Olney Cr.	OC	4	-6.467	12.3	157.4	705	287.3	299.8
73	Pahrmann Cr.	PA01	4	-6.159	12.3	153.4	705	19.8	na
92	Mosher Cr.	MS01	4	-6.083	12.3	152.5	705	29.9	17.3
152	Wright Cr.	WR01	3	-0.2660*	9.5	23.7	50	34.8	13.8
74	Illahee Cr.	IC01	3	-1.5581*	9.5	23.7	50	24.9	12.6
58	Barker Cr.	BA	2	-0.759	23	84.3	263	95.6	90.0
76	Sacco Cr.	SACCO	2	0.382	23	69.7	263	116.3	91.8
77	Sullivan Cr.	SL01	2	1.48	23	55.7	263	42.1	42.1
81	Beaver Cr.	BE-LOW	2	1.58	23	54.4	263	98.0	72.0
210	Springbrook Cr.	BISBC	5	1.229	11.1	58.9	294	194.1	97.7
193	Blackjack Cr.	BL-KFC	1	2.069	11	48.2	138	71.5	70.4
87	Chico Cr.	CH01	1	2.97	11	36.6	138	25.7	27.0
57	Anderson Cr.	AC	1	3.462	11	30.3	138	16.2	15.9
55	Gorst Cr.	GC-SC	1	3.497	11	29.9	138	85.4	79.2

na = no data available

* Factor score outside cluster bound, cluster median assigned

Table 2-11. Summary of stormwater basins for predicted and observed FC concentrations (fcu/100 ml).

DSN	Name	Location	Group	Ave Daily Flow CFS	Predicted 25th	Predicted Geomean	Predicted 75th	Observed Geomean	Observed n	Observed min	Observed max	Observed 25th	Observed 75th	Observed 90th
166	PSNS008	Inactive Ships	U/I	0.1	210	947	1255	428	12	1	6100	130	2970	11570
167	PSNS015	McDonalds NavSta	U/I	0.4	210	947	1255	1304	14	31	13000	601	5158	12178
170	PSNS082.5	Bldg 480	U/I	0.1	210	947	1255	1331	3	170	6600	1135	4350	14606
175	PSNS115.1	Dry Dock 1	U/I	0.1	210	947	1255	952	14	1	39000	385	5025	40974
174	PSNS101	Pier 5	U/I	0.1	210	947	1255	14	14	1	90000	1	194	1676
169	PSNS081.1	Bldg 455 "R" St.	U/I	0.1	210	947	1255	7602	13	1100	99000	3200	18000	44528
176	PSNS124	Dry Dock 3	U/I	0.1	210	947	1255	10	14	1	1300	2	16	220
177	PSNS126	Bldg 460 Pier 8	U/I	0.1	210	947	1255	2473	13	1	133000	1733	14000	124917
153	LMK164	National Ave	U/I	0.4	210	947	1255	576	15	23	11000	270	1650	4678
223	BST27	Evergreen Wy	U/I	0.2	210	947	1255	1239	9	290	4752	650	2200	4294
143	LMK020	Phinney Bay	U/I	1.1	210	947	1255	1539	21	69	19000	770	3200	10677
151	BST26	Oyster Bay	U/I	0.7	210	947	1255	609	14	54	2200	255	1550	2872
158	BST28	Callow Ave	U/I	1.7	210	947	1255	1091	11	30	32000	315	2500	12956
9	BST03	Stephenson Cr.	U/I	1.0	210	947	1255	657	20	100	3800	303	1490	2888
7	BST01	Pine Road	U/I	2.9	210	947	1255	513	17	37	79200	108	1714	6281
11	BST07	Campbell Way	U/I	0.8	210	947	1255	1603	11	290	5500	1013	3254	5505
16	BST12	Trenton Ave	U/I	0.6	210	947	1255	29	17	1	3600	3	450	910
220	BSTCSO16	Pacific Ave	U/I	0.1	210	947	1255	568	10	10	2376	538	1575	4874
217	LMK001	Bayshore St.	U/I	0.9	210	947	1255	196	20	8	1300	61	603	1351
99	LMK004	Old Town Silverdale	U/I	0.1	210	947	1255	155	21	5	2904	33	500	1542
216	LMK002	Sandpiper	U/I	0.2	210	947	1255	221	20	20	2500	59	650	1470
104	LMK026	Silverdale Hotel	U/I	1.8	210	947	1255	318	20	40	2640	121	718	1372
195	LMK055	Tracyton Blvd	U/I	1.1	210	947	1255	215	20	23	2100	71	645	1409
202	POBETH	PO Bethel Ave	U/I	0.1	210	947	1255	140	11	10	1100	46	376	881
32	POBAY	PO Bay St	U/I	0.4	210	947	1255	424	19	1	31000	64	3050	12443
183	POBLVD	Port Orchard Blvd.	U/I	0.3	210	947	1255	413	19	20	21000	146	2084	5757
213	LMK038	Manchester Ave	Rural	0.4	158	321	459	345	34	16	4000	169	670	2080
84	BILCSW	BI Lynwood Center	Rural	0.3	158	321	459	158	4	31	820	45	573	1272
45	BIFWSW	BI Fort Ward	Rural	1.3	158	321	459	459	4	300	1056	90	580	1440
199	LMK060	Tracy Ave	Suburban	1.2	62	140	263	61	20	8	980	12	157	478
31	POWILK	PO Wilkens St.	Suburban	0.4	62	140	263	64	19	7	640	19	260	430
27	LMK128	Subaru	Suburban	0.5	62	140	263	310	20	49	2900	124	658	1398
215	LMK122	Navy City Metals	Suburban	1.1	62	140	263	123	20	14	2100	41	301	738

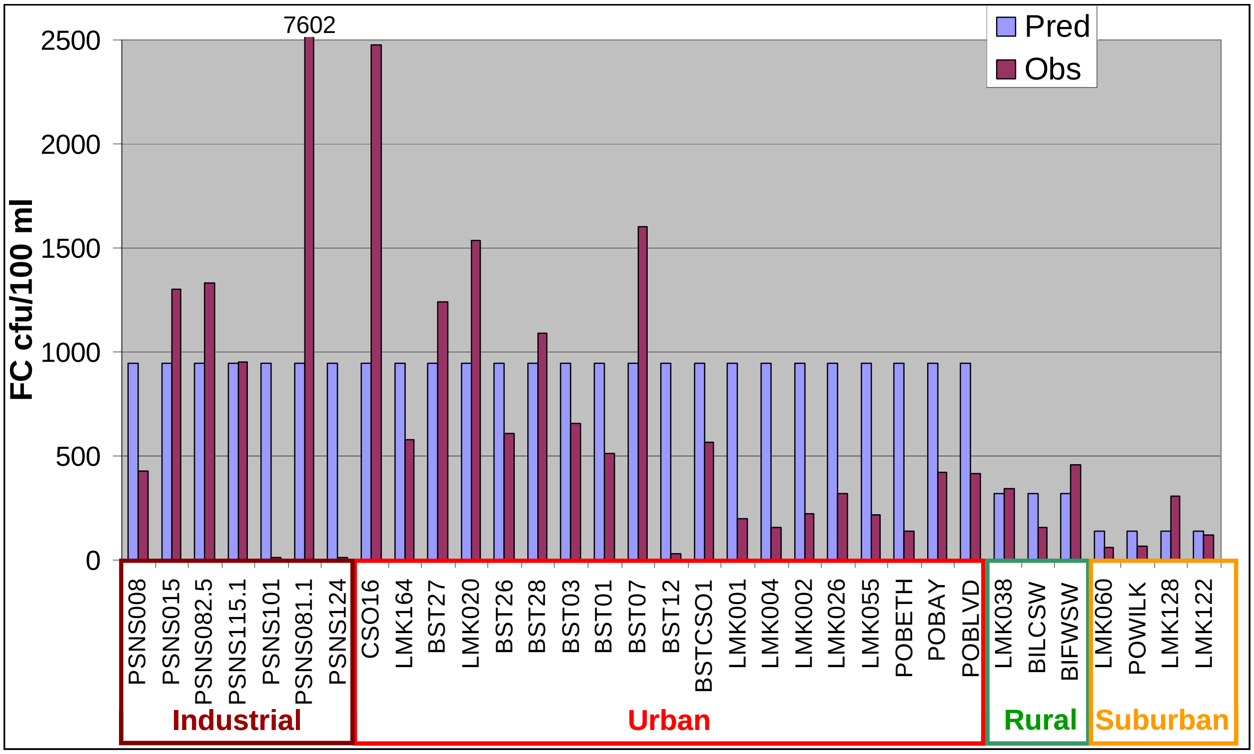


Figure 2-11. Predicted (Pred) and observed (Obs) FC geomean concentrations for industrial, urban, rural, and suburban stormwater outfalls in the Sinclair/Dyes Inlet Watershed.

Overall, we had a high degree of confidence that the statistical models could reliably predict the FC concentrations in streams and shoreline areas within the study area. Predicting FC concentrations in stormwater outfalls was less accurate because the stormwater systems were more variable. Though uncertainties were associated with these predictions, the uncertainty was within the limits of the uncertainty associated with the actual data. The abilility to obtain estimates of FC sources, without extrapolation, from the other drainage basins for which no data were available was another benefit. The statistical approach was based on empirical data from the watershed and benefited from combining the extensive data sets from the KCHD, Kitsap County SSWM, WDOH, and the ENVVEST studies, which were conducted with specific data quality objectives designed to fill information gaps and support the landscape-scale assessment (ENVVEST, 2002; Johnston et al., 2004; May et al., 2005). The k-cluster regression method proved to be very robust for estimating in-stream FC concentrations for streams based on the basin's LULC characteristics. Treating shoreline direct runoff areas the same as streams may underestimate the actual FC concentrations for heavily developed shoreline areas. The estimates of FC concentrations in stormwater systems were more uncertain; however, the stormwater approach was practical, took advantage of the available information, and provided a reasonable estimate of FC concentrations in stormwater systems.

Coupled together with the watershed-scale hydrology model, we deemed the results for predicting FC concentrations in streams, shoreline areas, and stormwater outfalls appropriate and applicable for simulating FC loadings into the receiving waters.

2.3 Modeling FC Loading from Waste Water Treatment Plants

Four waste water treatment plant (WWTP) outfalls discharge into the study area. The City of Bremerton has two permitted discharges: the main WWTP located in West Bremerton that discharges into Sinclair Inlet between Bremerton and Gorst, and the Eastside Treatment Facility (ETF) located in East Bremerton that discharges into the Port Washington Narrows (Ecology 2006a, COB, 2005). The City of Port Orchard/Karcher Creek Sewer District (Karcher Creek) WWTP[7] discharges into Sinclair Inlet near the mouth of Olney Creek (Ecology, 2007), and the Fort Ward/Sewer District No. 7 (Fort Ward) WWTP on Bainbridge Island discharges into Rich Passage (Ecology, 2006b). The treatment plants operate under NPDES Permits issued by Ecology with FC effluent limits of 200 cfu/100ml for a monthly average and 400 cfu/100ml for a weekly average based on a geometric mean of FC samples (Ecology, 2006a, 2006b, 2007). The permit requires the plants to submit monthly discharge monitoring reports (DMRs) that report flow (discharge volume) and FC concentrations measured periodically in grab samples collected from the plants' effluent. Discharges from the ETF were not included for the study period.[8]

Data from DMRs submitted from the WWTPs from October 2001 to September 2003 were used to estimate FC loadings into the receiving waters from the plants (Figure 2-12)[9]. The load ($WWTP_{Load}$, in FC units or counts per second) was calculated by multiplying the daily flow (MGD) by the point estimates of FC:

$$\mathrm{WTTP}_{\mathrm{Load}}\,[cfu/s] = FC\left[\frac{cfu}{100ml}\right]\times MGD\left[\frac{10^6\,gal}{d}\right]\times\left[\frac{3785.4ml}{gal}\times\frac{1d}{86400s}\right] \quad [3]$$

A point-to-point interpolation was used to develop continuous estimates of the FC loading from each of the WWTPs from 1 October 2002–30 September 2003 (Figure 2-13). These values were used to simulate the discharge loads from the WWTPs for the WY2003 simulations.

The FC loads from the WWTPs were also estimated for simulations of the 2004 storm events. Flow and FC data were not available for the April 20-22, 2004 storm event, so the WWTP loads were set to the 25^{th}, 50^{th} (geomean), and 75^{th} percentile of the FC loads obtained from the DMRs (Figure 2-14). Grab samples of FC concentrations in the effluent (Table 2-12) and measurement of flow were obtained from the Bremerton and Karcher Creek WWTPs during the May 26 and October 19 2004 storm events, and these data were used to estimate the loads for simulations of the May 2004 (Figure 2-15) and October 2004 (Figure 2-16) storm events. No additional data were available for the Fort Ward WWTP, so the loads were set to the percentiles obtained from the DMRs (Table 2-12) for all the simulations of the 2004 events.[10]

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[7] In November 2007, the West Sound Utility District was formed by the consolidation of Annapolis Water District and Karcher Creek Sewer District.

[8] A total of 7.9 million gallons from seven discharge events, two in Jan. 2003 and five in March 2003, were reported discharged from the ETF during WY2003 (COB 2005).

[9] The DMRs used to calculate FC loading for the Fort Ward (Kitsap County Sewer District 7) WWTP were from the City of Bainbridge Island WWTP; this error resulted in about a factor of 10 increase in FC loading from the Fort Ward WWTP than what actually occurred.

[10] Due to a transcription error, the loading for Fort Ward was inadvertently set to 758 instead of 6758 for the 75^{th} percentile simulation of the Oct 2004 storm event. This had negligible effects on the simulation result.

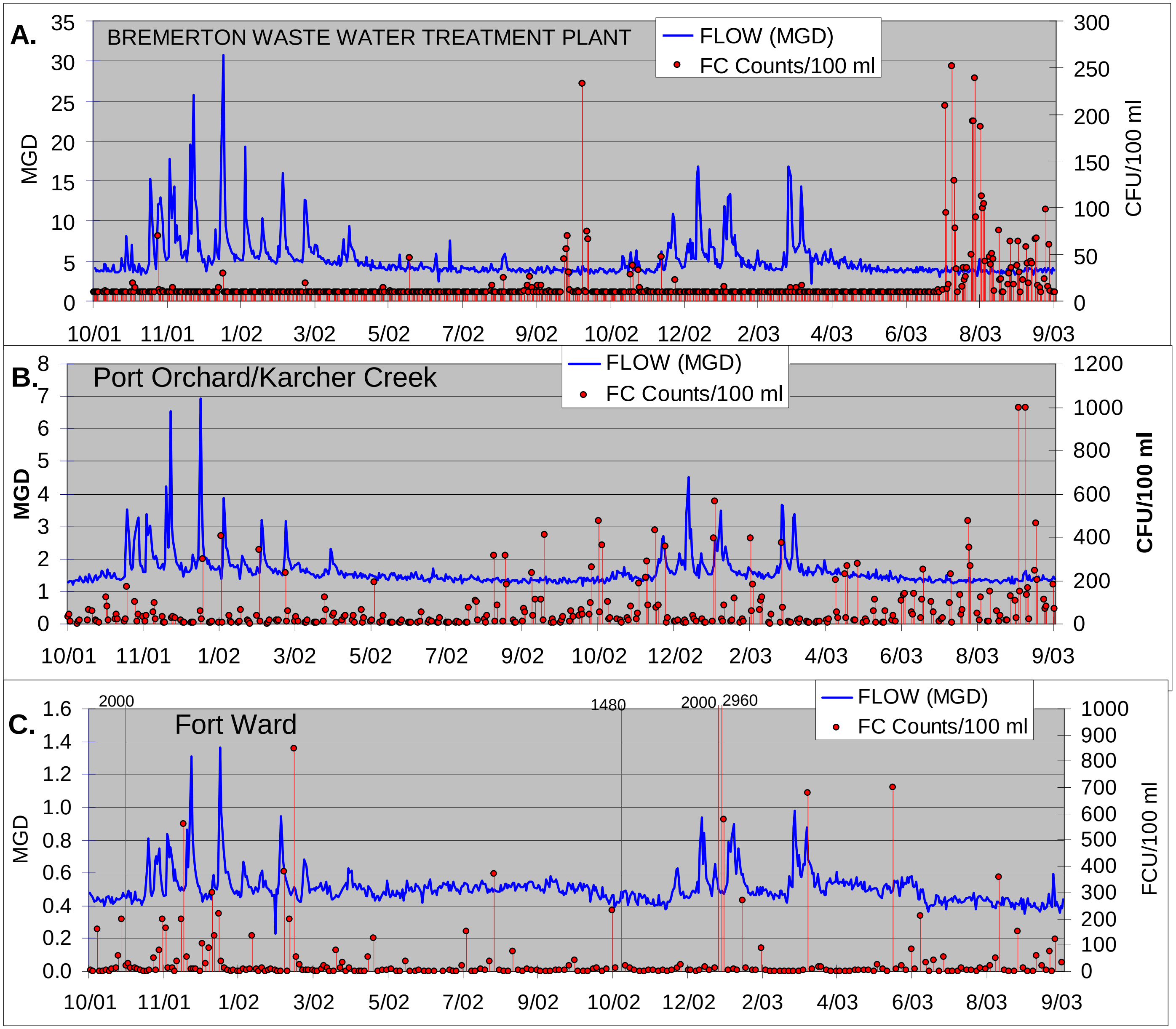


Figure 2-12. Fecal coliform (CFU) and flow in million gallons per day (MGD) data report from DMRs submitted by the Bremerton (A), Port Orchard/Karcher Creek (B), and Fort Ward (C) WWTPs from October 2001 to September 2003. (Note that DMR data from the City of Bainbridge Island WWTP were inadvertently used for the Fort Ward WWTP.)

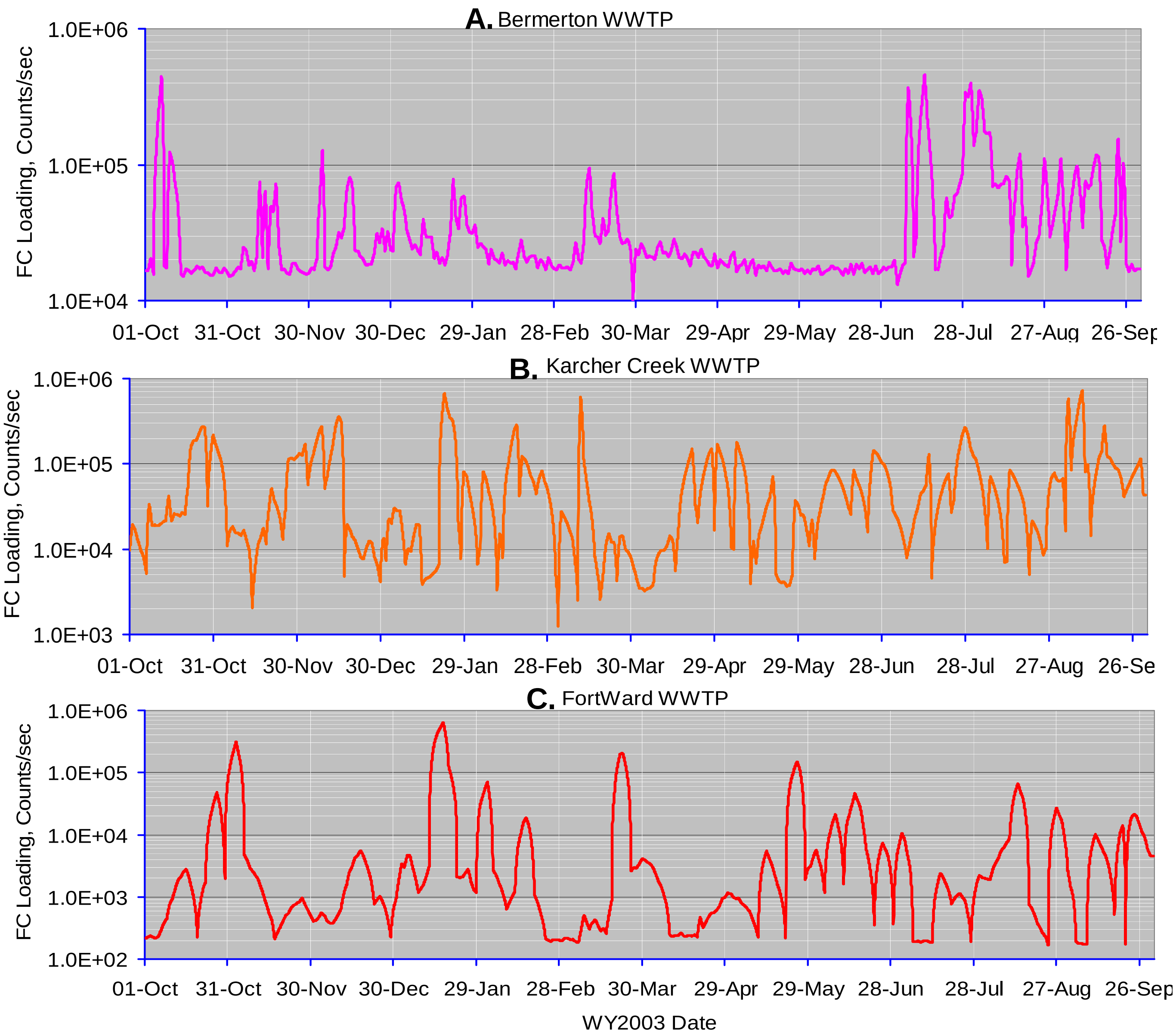
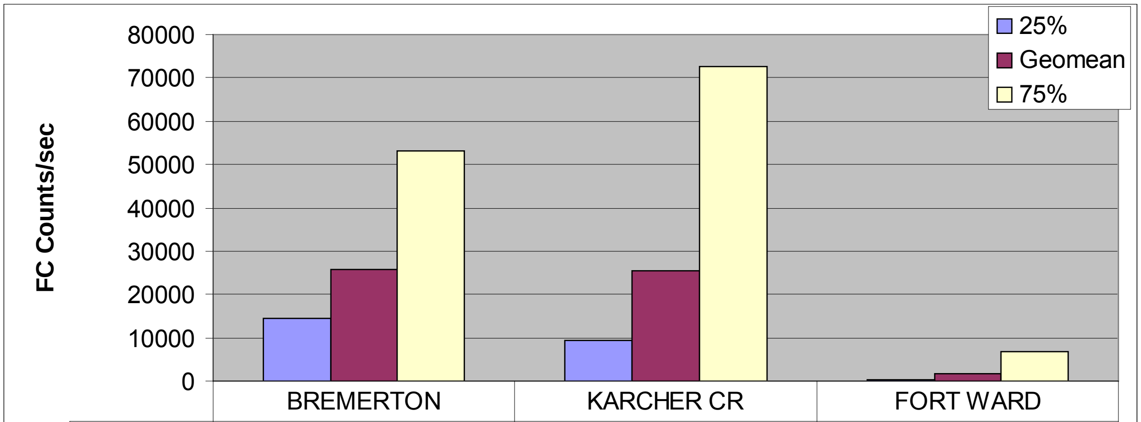


Figure 2-13. Simulated FC loads (counts/sec) from the Bremerton (A), Port Orchard/Karcher Creek (B), and Fort Ward (C) WWTPs for WY2003. (Note that DMR data from the City of Bainbridge Island WWTP were inadvertently used for the Fort Ward WWTP.)



	BREMERTON	KARCHER CR	FORT WARD
25%	14325	9304	369
Geomean	25685	25568	1573
75%	53115	72771	6758

Figure 2-14. The 25th, 50th (geomean), and 75th percentile of FC loads obtained from the DMRs for WWTP discharges into Sinclair and Dyes Inlets. (Note that DMR data from the City of Bainbridge Island WWTP were inadvertently used for the Fort Ward WWTP.)

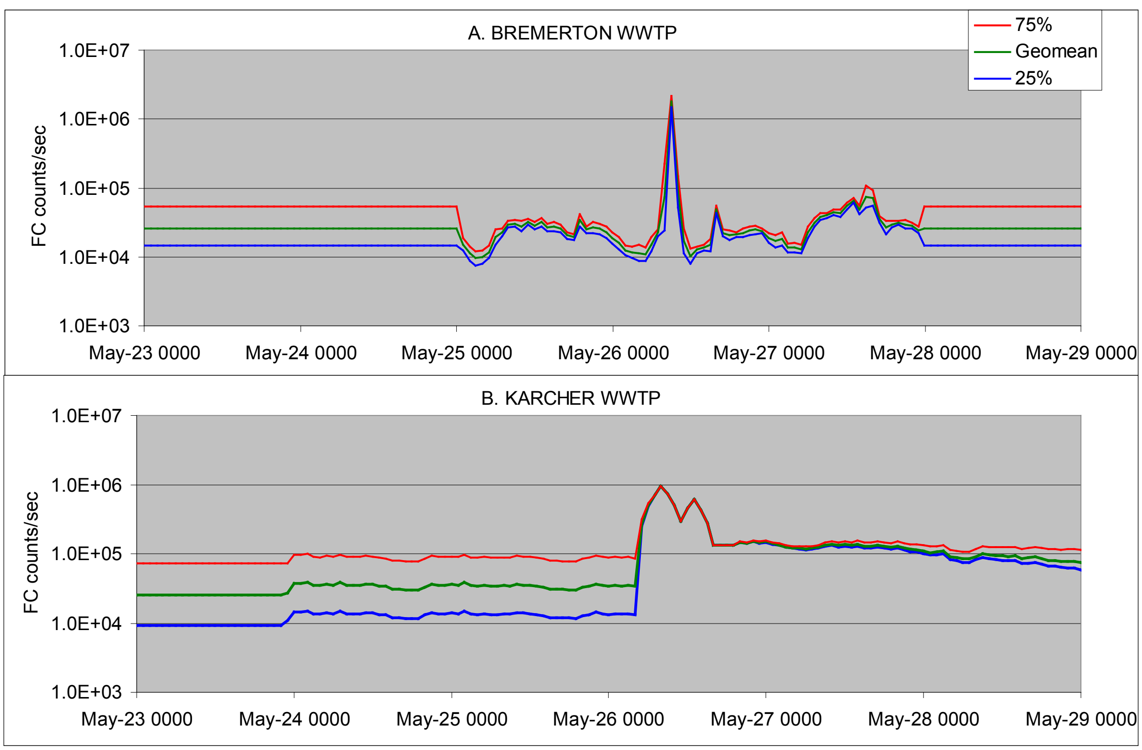


Figure 2-15. Time series of FC loads used to simulate discharges from the Bremerton (A) and Port Orchard/Karcher Creek (B) WWTPs for the May 2004 storm event.

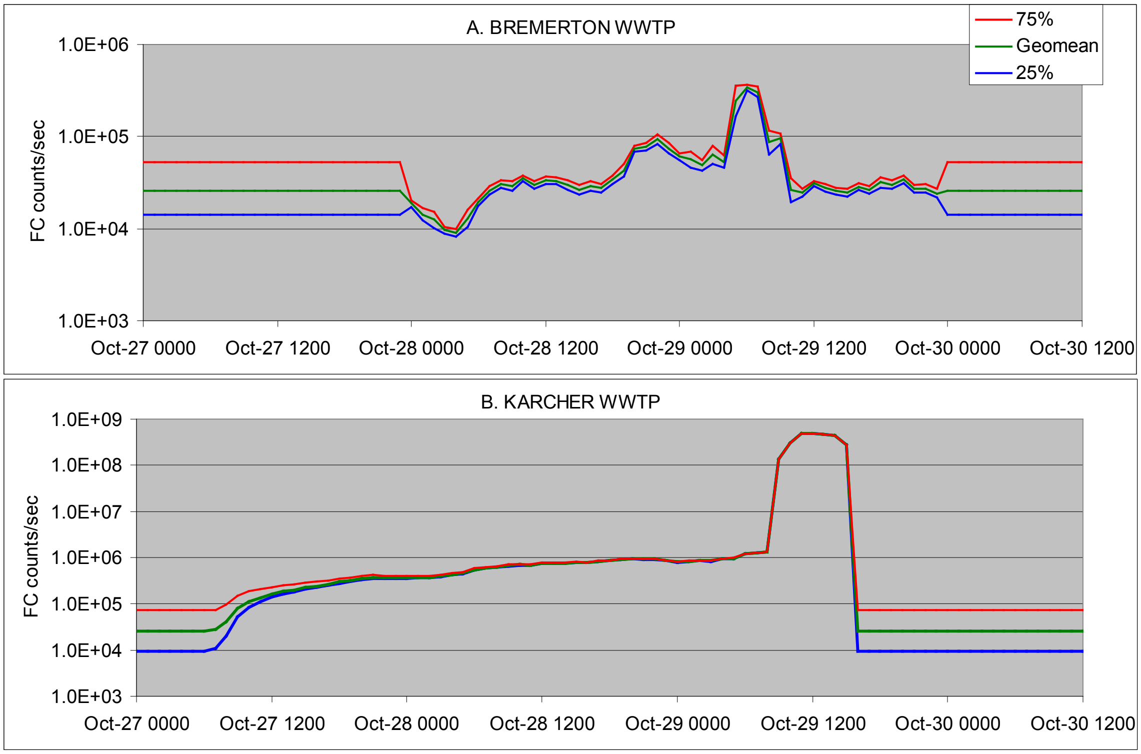


Figure 2-16. Time series of FC loads used to simulate discharges from the Bremerton (A) and Port Orchard/Karcher Creek (B) WWTPs for the October 2004 storm event.

Table 2-12. The FC concentrations (cfu/100ml) measured in effluent samples collected from the Bremerton and Karcher Creek WWTPs during the May 2004 (A) and October 2004 (B) storm events. The 25th, 50th (geomean), and 75th percentiles were calculated from the log-transformed data.

					fcu/100ml		
A. MAY 2004					Percentiles		
SAMPLE_DATE	SITE_NAME	FC	QA	log(FC)	25	geomean	75
MAY 2004							
5/26/2004 8:40	BREM-WWTP	6		0.7782			
5/26/2004 9:25	BREM-WWTP	540		2.7324			
5/26/2004 10:10	BREM-WWTP	20		1.3010			
5/26/2004 11:48	BREM-WWTP	3		0.4771			
					4.39	21.00	100.48
5/26/2004 8:25	KAR-WWTP	1100		3.0414			
5/26/2004 10:50	KAR-WWTP	340		2.5315			
5/26/2004 12:45	KAR-WWTP	730		2.8633			
5/26/2004 15:35	KAR-WWTP	180		2.2553			
					272.40	470.83	813.82
B. OCT 2004					Percentiles		
SAMPLE_DATE	SITE_NAME	VALUE	QA	log(FC)	25	geomean	75
10/19/2004 7:30	BREM-WWTP	86		1.9345			
10/19/2004 8:30	BREM-WWTP	11		1.0414			
10/19/2004 9:30	BREM-WWTP	39		1.5911			
10/19/2004 10:30	BREM-WWTP	6		0.7782			
					9.56	21.69	49.21
10/19/2004 8:22	KAR-WWTP	1200	J	3.0792			
10/19/2004 11:22	KAR-WWTP	400000	NC	5.6021			
10/19/2004 14:05	KAR-WWTP	400000	NC	5.6021			
10/19/2004 14:20	KAR-WWTP	60000	NC	4.7782			
					9049.42	58259.01	375064.09

J = the value is an estimate, the “true” value may be greater than or equal to the reported results
NC = too numerous to count, value is an estimate; The colonies were a solid mat and had run together making it impossible to distinguish individual colonies.

2.4 Modeling FC Fate and Transport in Sinclair and Dyes Inlets

The numerical model, Curvilinear Hydrodynamics in Three Dimensions (CH3D), was chosen for the modeling study of Sinclair Inlet. CH3D is a mathematical, three-dimensional, time-varying hydrodynamic model that was developed by the U.S. Army Corps of Engineers (USACE) Waterways Experiment Station (WES), Coastal and Hydraulics Laboratory (CHL) in Vicksburg, Mississippi, for the Chesapeake Bay (Johnson et al., 1991). The CH3D model was applied to simulate the circulation and vertical mixing processes for the Sinclair and Dyes Inlet system. The details of the model’s numerical calculations and user specified inputs are provided in Brown (2001); initial calibration and verification were reported in Wang and Richter (1999); and the hydrodynamic model validation was documented in Richter (2004). A module to simulate FC die-off as a function of salinity, temperature, mixing depth and sunlight was added to the model code (CH3D-FC) to simulate the fate and

transport of FC bacteria in the inlets (Johnston et al., 2004). Previously, CH3D-FC was used to simulate combined sewer overflow (CSO) events in the Port Washington Narrows (Wang et al., 2005) and the results were instrumental in the reopening of shellfish beds in Dyes Inlet (WDOH 2003a, b, c). The following is a brief summary of the model's application to model fate and transport of FC bacteria Sinclair and Dyes Inlets. Supporting information, including reports documenting details of calibration and verification analysis, plots of verification results, and model simulation files, is available on the distribution CD or via the internet (Table 1-1).

2.4.1 CH3D Hydrodynamic Model Development

The model code used for the Sinclair and Dyes Inlets study is currently maintained by the Space and Naval Warfare Systems Center Pacific (SSC Pacific) in San Diego, California. The model resolves depth in the vertical direction using a z-grid (Brown, 2001; Wang and Richter, 1999), and the code has been modified to output the results in the network common data format (netCDF) (Johnston and Wang, 2005, 2006). The inlet-wide circulation and vertical mixing processes modeled include tides, wind, density effects (salinity and temperature[11]), freshwater inflows, turbulence, and the effect of the earth's rotation. To adequately represent the vertical turbulence, a second-order turbulence model based on the assumption of local equilibrium of turbulence was employed. The boundary-fitted coordinate features of CH3D were used to develop an accurate and economical grid scheme that resolved the deep navigation channels, the shallow areas of the inlets, and the irregular shoreline (Brown, 2001; Wang and Richter, 1999).

The governing equations in CH3D are the shallow-water equations transformed into the curvilinear plane. Several assumptions are made in the model formulation, including the hydrostatic (shallow water) approximation, the Boussinesq approximation, and incompressibility (Vallis, 2006). The model domain is divided into many small numerical 3-D grid cells, and velocity and density are assumed constant within each cell. Horizontal density gradients in the momentum equations are treated explicitly. Bottom shear stress is approximated using a Manning–Chezy formulation with Manning's n coefficient assigned as a function of local water depth. It is further assumed that the direction of bottom shear stress is exactly opposite to the depth-averaged velocity (Wang and Richter, 1999; Brown, 2001).

For transport of conservative solutes, a transport equation is solved for each conservative species, C_i. Solutes are assumed to be dilute, thus the solute transport equations are uncoupled from the hydrodynamics. Furthermore, the transport equation is solved at one time step behind the continuity and momentum equations, effectively uncoupling the transport equation (Wang et al., 1998, Wang, 2001). This approach is valid because baroclinic (density) forcing changes less rapidly than barotropic (static head pressure – tidal) forcing.

The CH3D model uses curvilinear boundary-fitted numerical grids in the horizontal plane (Figure 2-17A). All variables in CH3D are defined on a staggered grid. Water surface elevation, salinity and solute concentrations are defined at the center of a grid cell (i, j), while the *U* velocity is defined at (i + ½, j), the *V* velocity at (i, j + ½), and water depths at (i + ½, j) and (i, j + ½).

For the vertical direction, the water column was divided into multiple layers of equal thickness. The number of layers varies from over 10 layers for deeper regions to one layer for extremely shallow regions (depth < 3 meters, Figure 2-17B). CH3D solves the time-dependent differential

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[11] Temperature was input as constant which varied as a function of time of year.

equations for water surface displacement ($\varsigma(x,y,t)$), 3-D velocities ($u(x,y,z,t)$, $v(x,y,z,t)$), temperature, salinity and density (see Brown, 2001, for equation formulations). CH3D is capable of handling a variety of external forcing, including tides, winds, tributary flows, point and non-point sources, as well as baroclinic effects due to density differences between freshwater inflows and saline inlet water. CH3D accounts for the wind field, which introduces shears over the water surface, driving water mass transport in addition to tidal forcing. Flows in the inlet are driven at the model boundaries. The k-ε turbulence closure scheme is used to estimate the vertical diffusivity, a parameter governing the mixing in the water column (Wang and Richter, 1999; Brown, 2001).

A grid-generation program (SMS, 2008) was used to generate the curvilinear model grids with grid cells of different sizes, ranging from 40 to 100 meters inside the inlet to over 200 meters in Port Orchard and Rich Passage (Figure 2-17). CH3D was initially set up in Dyes and Sinclair Inlets at two different resolutions. The first, employing 1345 nodes and designated as the 91 x 83 grid (for 91 by 83 nodes, 1345 of which are in water) was set up and run in 1998. The second, employing 2481 nodes and designated as grid 91 x 96, was set up and run in 2001. The second, higher resolution grid was created to address model inaccuracies at the confluence of Sinclair Inlet and Washington Narrows, a region where water velocity changes abruptly over a short distance (Richter, 2004). The model time-step was partially limited by the small grid cells inside Sinclair Inlet, and a time step of 60 seconds was used, which produced stable results over all the simulation periods.

While grid cell size varied in the horizontal direction, grid size (Δz) in the vertical direction (water column) was fixed with $\Delta z = 3$ meters (Figure 2-17B). This depth resolution was chosen based on experimental results with the model and the fact that tidal amplitudes in the inlets are large, reaching 2.8 meters during spring tides. For $\Delta z < 3$, model runs would become unstable for periods of very low tides when surface grid cells become exposed. The grid size of 3 meters was chosen to always keep the surface layers wet, even during the lowest spring tides.

Tidal forcing for the model was implemented by generating the tides at the model boundaries in Clam Bay and Brownsville using the software TIDE1 (Micronautics, Inc., Rockport, Maine). Generated tides were processed, and harmonic constants of the 16 major tidal constituents were extracted. The extracted tidal harmonic constants were modified to reproduce tides at the Clam Bay and Brownsville boundaries.

2.4.1.1 Hydrodynamic Model Verification for Sinclair Inlet

The CH3D model was set up to simulate tides and currents measured by the United States Geological Survey (USGS) from February to April and July to August 1994 (Cheng, 1994). Initial model results were compared with the measured data for the first period (February to April) for model calibration. Hydrodynamic model verification was conducted using water velocity data collected from a vessel-mounted acoustic Doppler current profiler (ADCP) (RD Instrument, 1200 kHz, narrow band) that measured water velocity relative to the bottom (RDI, 1989) primarily in Sinclair Inlet (Katz et al., 2004). The vessel mounted ADCP was programmed to collect water column velocities at 1 meter vertical resolution to the bottom five times per second. Data were averaged over 10 seconds, yielding a velocity precision of approximately 1.8 cm/sec (RDI, 1989). The vessel typically steamed at 1 m/s (2 knots), yielding a horizontal resolution of approximately 10 meters. On three cruises in September 1997; March 1998 and July 1998; a total of 632,424 vertical profiles were collected (Katz et al., 2004).

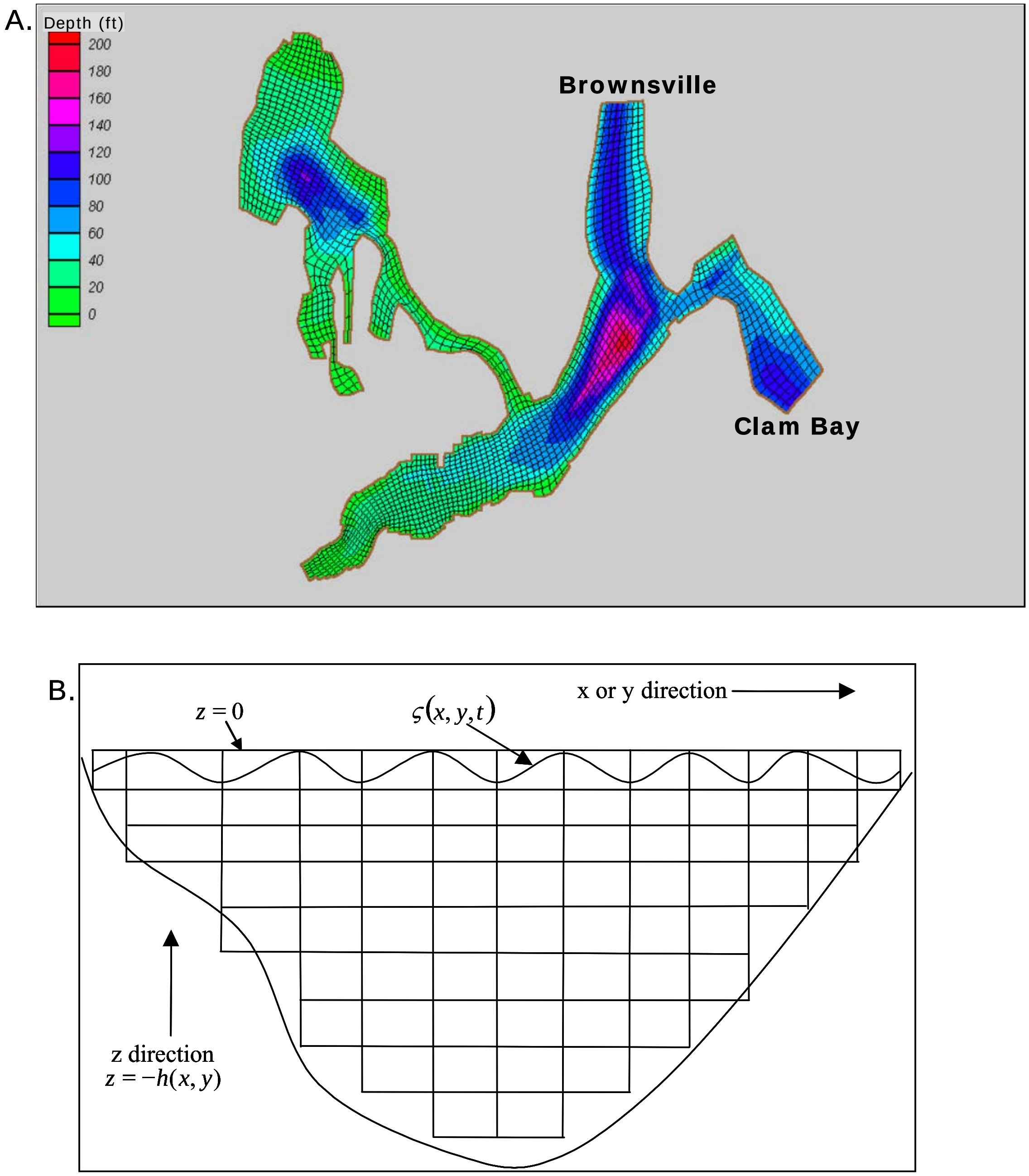


Figure 2-17. The CH3D numerical grid for Sinclair and Dyes Inlets (A) and schematic of a vertical cross-section (B).

Vessel position was determined via a differential Global Positioning System (GPS), recorded simultaneously with the ADCP data. In addition, data were also collected from a wideband 1200-kHz ADCP (RDI, 1996) anchored on the bottom and looking up at three different locations in Sinclair Inlet from 1997 to 1998, averaging 2 months deployment at each location. Water column velocities were collected at 0.5 meter vertical resolution to the surface three times per minute. Data were averaged over 5 minutes, yielding a velocity precision of approximately 1.8 cm/sec (RDI, 1996). A total of 51,480 vertical profiles were collected in this manner.

ADCP data were averaged into 3-meter depth bins to match the depth resolution output by CH3D. The data were then merged with the CH3D output by time, spatial location (nearest model node), and depth. Model predictions were compared to current measurements per 3-meter depth interval and as water column means. Comparisons were sorted by tidal stage as well: the tidal cycle was divided into 12 stages based on tidal slope, ranging from slack low water, incoming tide, slack high water, outgoing tide, and a second low slack water. The results obtained for tide stage 5 (end of flood) are shown in Figure 2-18. Overall, the accuracy of the 91 x 83 grid compared to the 91 x 96 grid ($p > 0.14$, Wilcoxon rank sum test) was the same, so the results from the 91 x 96 grid were used for the subsequent TMDL modeling because it offered better spatial resolution with similar accuracy.

For the bulk of Sinclair Inlet, away from the shore, CH3D predicted currents within 2 cm/hr to 5 cm/hr of measured values. CH3D tended to overpredict water speed at the mouth of Washington Narrows and underpredict water speed near the shore. The latter effect is probably due to wake aliasing from the boat collecting ADCP data. The predictions of current direction followed the expected pattern but deviated from measurements, probably because some of the measurements could have been aliased by the boat wake or reflect local wind and input stream conditions. The predicted current speed and direction, without the impact of local weather or boat disturbances, may better represent mean current conditions in Sinclair Inlet. (See Richter, 2004, for details of verification for current predictions in Sinclair Inlet and Port Washington Narrows.) Suplemental information is available on the distribution CD or via the internet (Table 1-1).

2.4.1.2 Hydrodynamic Model Verification for Dyes Inlet

During the application of CH3D to model CSO discharges in the Port Washington Narrows (Wang et al., 2005), the CSO subworking group identified the need for data on current and transport patterns in upper Dyes Inlet. Therefore, the participants cooperatively executed a drogue, current meter, and dye-release study in Dyes Inlet and the Port Washington Narrows to provide data to calibrate and verify the hydrodynamic model for Dyes Inlet (WDOH, 2000; Wang et al., 2005).

The drogue and current meter study was completed in Fall 2000. A series of drogue releases at the start of an incoming tide were conducted in the Port Washington Narrows (23 October 2000), at Rocky Point (20 October 2000), in Ostrich Bay (13 October, 2000), and adjacent to Windy Point (24 October 2000) in Northern Dyes Inlet (ENNVEST, 2001). For each study, surface drogues were released during flood tides and each had a Global Positioning System (GPS) device onboard. The drogue trajectories were obtained by downloading the GPS data to a PC after the drogues were retrieved (within 1 to 6 hours). An ADCP current meter was deployed from 12 October to 14 November 2000 at the mouth of Dyes Inlet near Rocky Point to measure vertical profiles of current from the bottom to the surface of the water column. Additionally, two S4 current meters were deployed in Ostrich Bay to measure currents at a fixed depth. Trajectory data from the drogues were compared with the predicted results from CH3D. Local winds and tides were included in the analysis, and their effects on the drogue drifts were quantified. Based on these results, the grid for Dyes Inlet was refined for the 91 x 96 grid. The refined model was able to reproduce the drogue trajectories and ADCP current velocities and directions with very good accuracy (Figure 2-19).

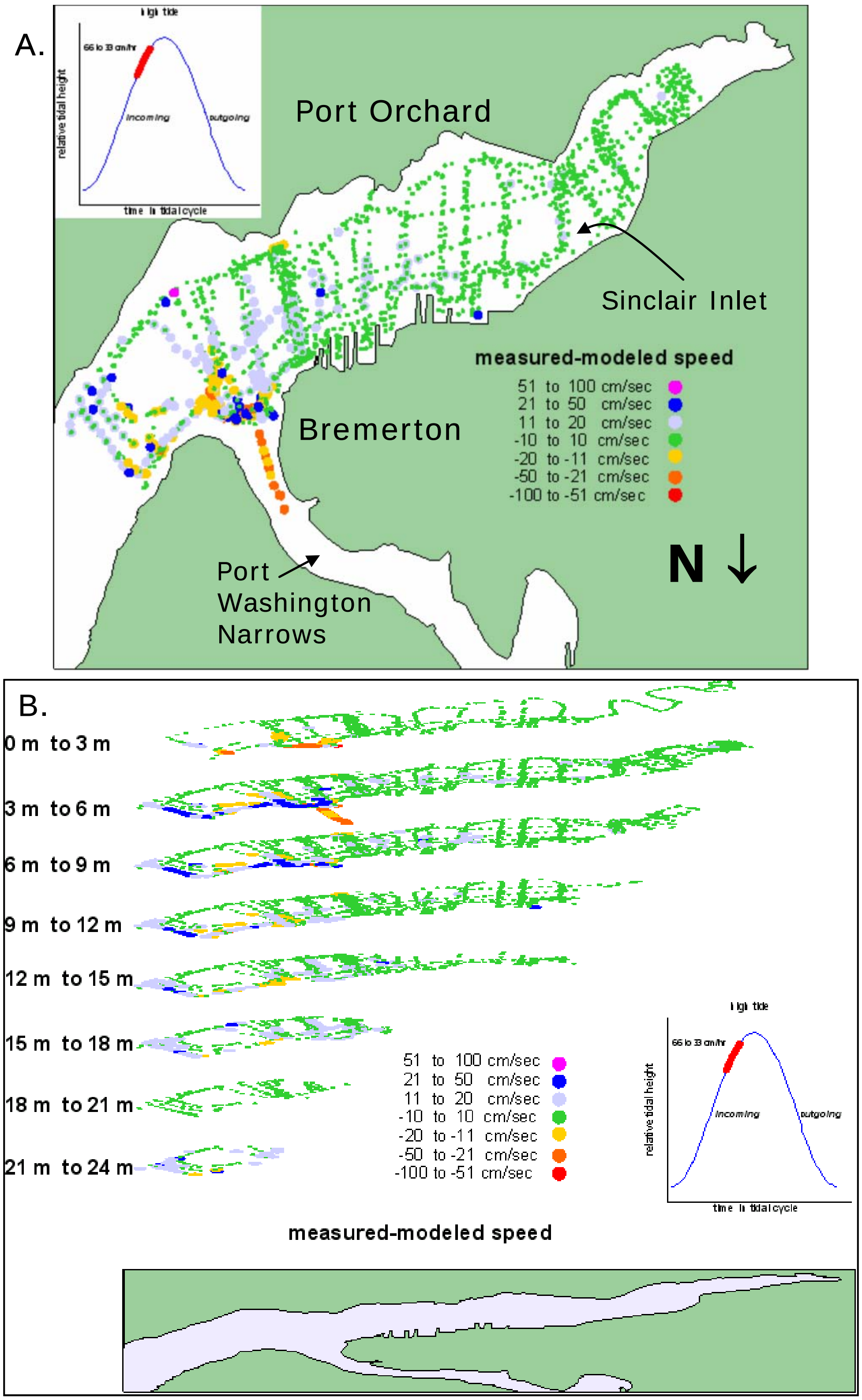


Figure 2-18. Absolute difference between modeled and measured current speed at all depths (A) and horizontally smoothed and extrapolated absolute difference by depth (B) during tide condition 5 (end of flood) based on 3859 observations (from Richter, 2004).

The dye release study was conducted on 12 March 2002 to simulate a CSO discharge event in the Port Washington Narrows during the incoming tide (ENVVEST, 2001). Dye injection began at the beginning of a flood tide and continued until slack tide from the ETF outfall in the center of the Port Washington Narrows. Drogues were periodically deployed at the injection point to mark the plume while "Vessel A" tracked the plume up the Port Washington Narrows and "Vessel B" conducted continuous transects across the mouth of Dyes Inlet at Rocky Point. Both vessels were outfitted with real-time monitoring equipment and positioning systems (GPS) to continuously record the boat position, dye concentration, temperature, salinity, dissolved oxygen, turbidity, and pH. The plume was tracked for about 8 hours (until nightfall). Current speeds were obtained from the ADCP moored in the mouth of Dyes Inlet at Rocky Point. Model predictions showed good agreement with the observed data (Wang et al., 2005).

2.4.1.3 Summary of Hydrodynamic Model Verification

The model verification for CH3D was very rigorous. There were numerous observations of current velocity (> 600,000 vertical profiles) over the entire tidal range taken at a large variety of locations and depths throughout the inlets (mainly Sinclair Inlet), during different seasonal time periods, and over all phases of the spring-neap tide cycle. Critical locations within the inlets were intensely monitored, including the confluence of the Port Washington Narrows and Sinclair Inlet, the connection between the Port Washington Narrows and Dyes Inlet at Rocky Point, inner Ostrich Bay, the main basin of Sinclair Inlet, and numerous marine and nearshore locations throughout the inlets. Current data were also collected utilizing different methods, including underway ADCP surveys, bottom moored ADCPs, fixed current meters, drogue releases, and a dye study. Based on this enormous amount of data, we were highy confident that CH3D could simulate currents and tides with very good accuracy for most of the inlets.

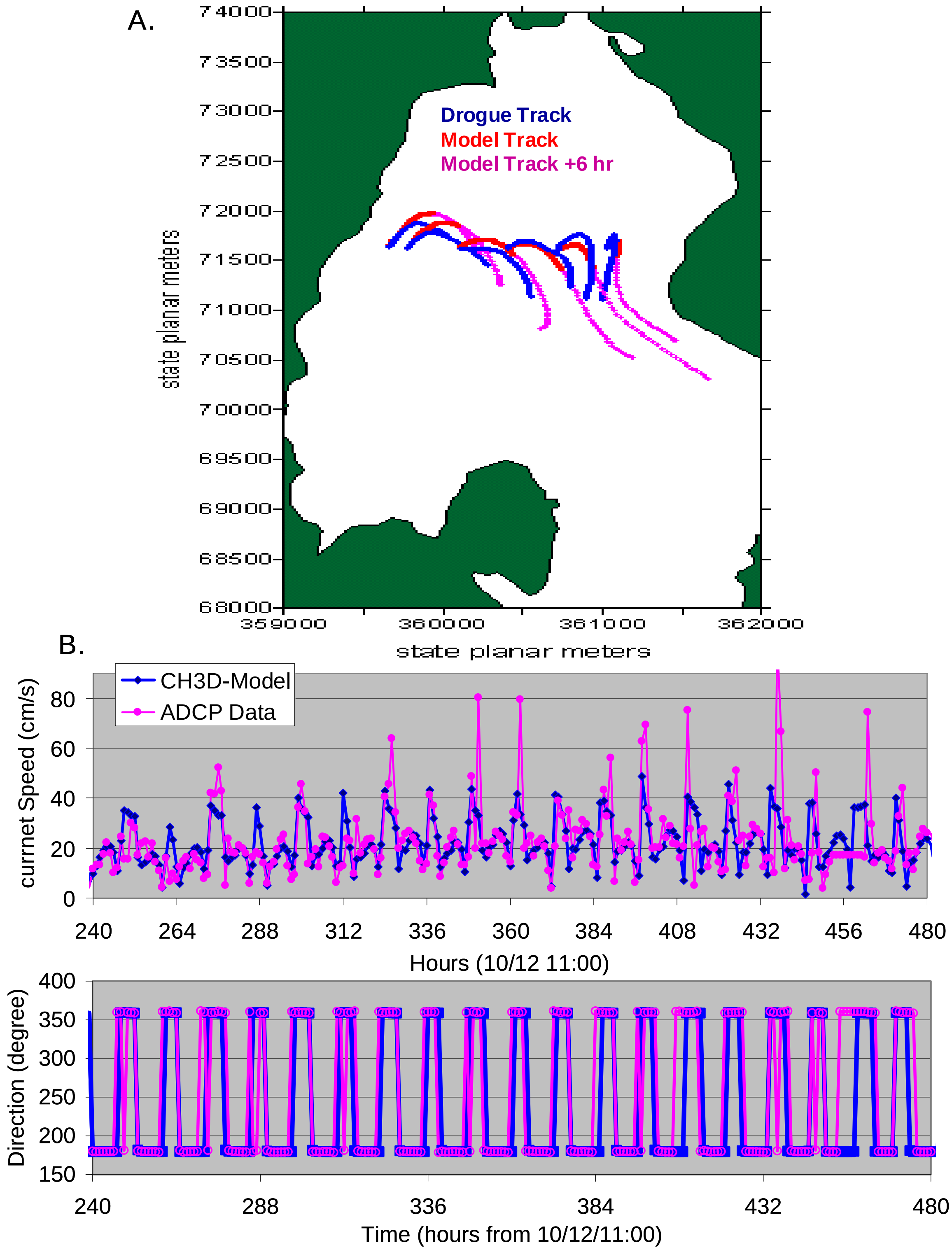


Figure 2-19. Observed and simulated drogue tracks in Dyes Inlet (A) and observed and simulated current velocities and direction for Rocky Point at the mouth of Dyes Inlet (B) (from Wang et al. 2005).

2.4.2 CH3D-FC Model Development

The kinetics of FC die-off has been described by Mancini (1978), which is an empirical formula derived from comprehensive datasets. Mancini's equation correlates FC death rate with salinity, temperature and light. A module to simulate FC die-off as a function of salinity, temperature, mixing depth, and sunlight (Mancini Equation, Figure 2-20) was added to the CH3D model code to create CH3D-FC:

$$C_t = = C_0 e^{-kt} \qquad [4]$$

Where:

C_t = surviving concentration [cfu/100 ml]

C_0 = initial concentration [cfu/100 ml]

t = time

k = bacterial death rate

$$= [0.8 + 0.006(S)] \times 1.07^{(T-20)} + \frac{I}{K_E H}[1 - e^{-(K_E H)}] \qquad [5]$$

$$= [0.8 + 0.006(S)] \times 1.07^{(T-20)} + Ie^{-(K_E Z)} \qquad [6]$$

S = percent seawater

I = incident radiation at water surface [Langleys J/m²]

T = temperature [°C]

K_E = light extinction coefficient of photosynthetically active radiation (PAR)

H = mixing depth [m]

Z = model depth [m]

The mixing depth H of the water column, the light extinction coefficient K_E averaged over 400- to 700-nm wavelength (photosynthetically active radiation [PAR]), and the incident light levels at the water surface, are most important in this equation. The mixing depth of the water column can be estimated by measuring and modeling the water density profile. The second term of equation ([5]) was reformulated to model light extinction as a function of model depth (*Z*) and the light extinction coefficient of PAR was estimated by measuring the secchi disk depth (a white and black disk lowered in the water column to a depth where it disappears from site) as:

$$K_E = (0.757/\text{secchi depth}) + 0.07 \;\; [\text{Langleys J/m}] \qquad [7]$$

A further modification was employed to estimate the extinction coefficient of blue light as a proxy for ultraviolet radiation from K_E that can be substituted as a more conservative value for K_E (Bukata et al, 1995):

$$K_{Blue} = 1.3K_E - 0.05 \qquad [8]$$

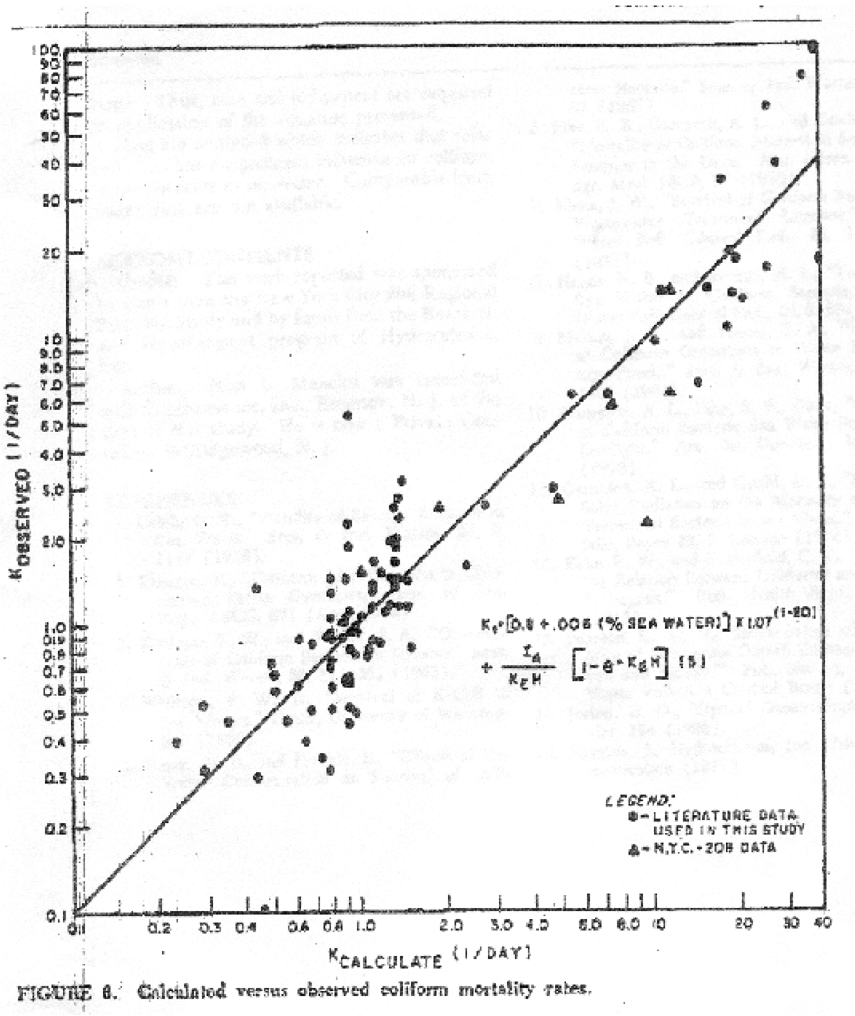


Figure 2-20. Calculated versus observed FC die-off rates (from Mancini, 1978).

The Mancini equation has been incorporated into many pathogen fate models and appears to hold for Enterococcus die-off rates as well (USEPA, 2001; Noble, Lee, and Schiff, 2002). Estimates of solar radiation, in Langleys, were based on average values from the literature (SERI, 1998). Salinity, temperature and secchi disk data collected in Sinclair and Dyes Inlets by Ecology from 1990 to 1995 (Ecology, 2008b) were combined with a 30 year average, monthly mean irradiance value to evaluate their effect on the range of likely *k* values (Figure 2-21, Wang et al., 2005). The seasonal variation in FC die-off rate in the inlets for depths of 1 m to 10 m showed that the lowest k values occur in the winter months (Figure 2-22A). Lower k values increase the time, in days, to reach 90% of bacteria extinction (Figure 2-22B). Based on this analysis, sunlight (incident radiation) and water clarity were the two most important variables controlling FC die-off in the receiving waters of the inlets.

The quality of the receiving waters will be dependent on the bacterial load being discharged from stormwater, streams, WWTPs, and CSOs; the rate of mixing into the water column (dispersion); and the extinction rate of the bacteria.

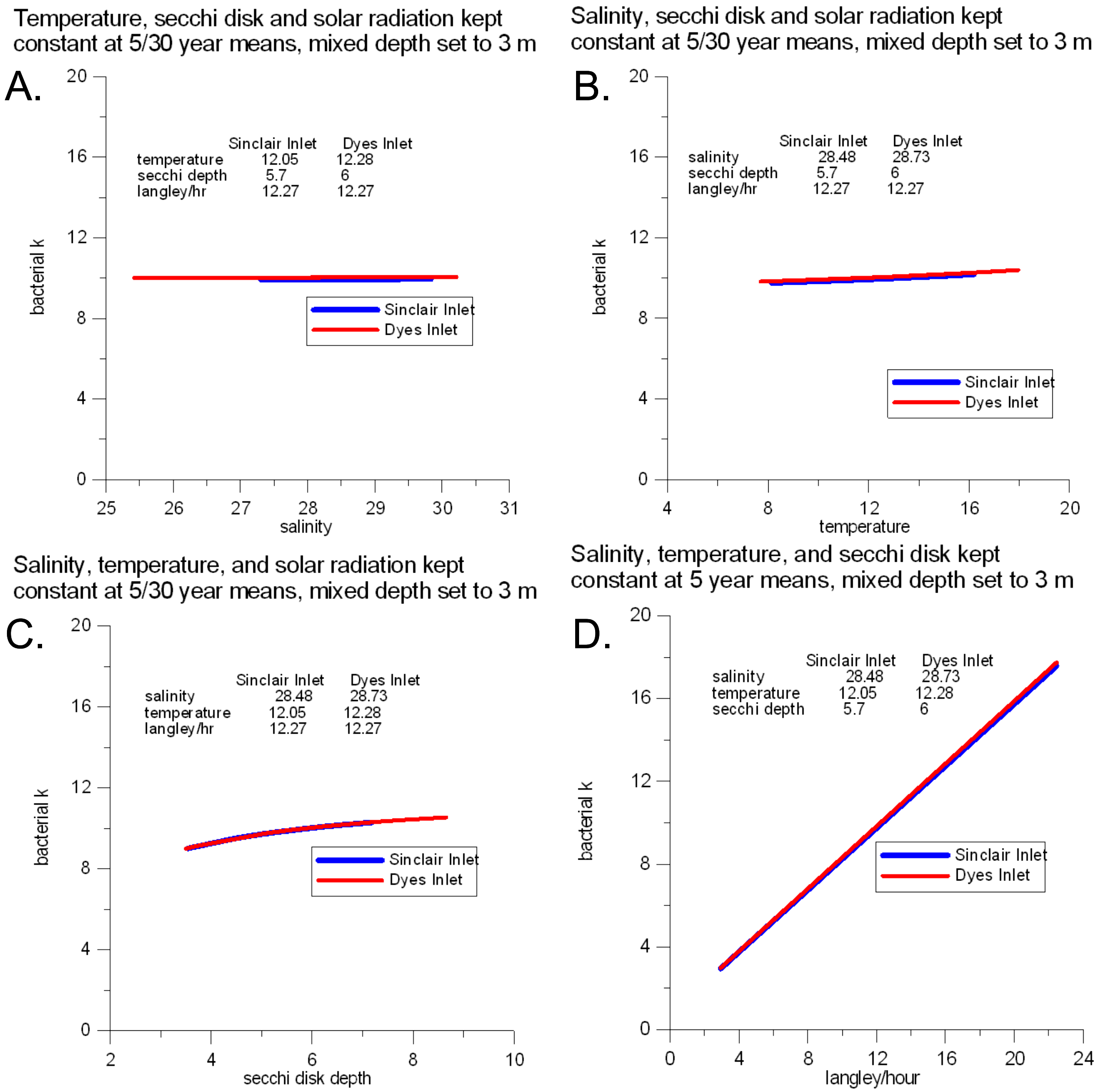


Figure 2-21. The effect of salinity (A), temperature (B), secchi disk depth (C), and solar radiation (D) on FC bacterial die-off rate (bacterial *k*) (from Wang et al., 2005).

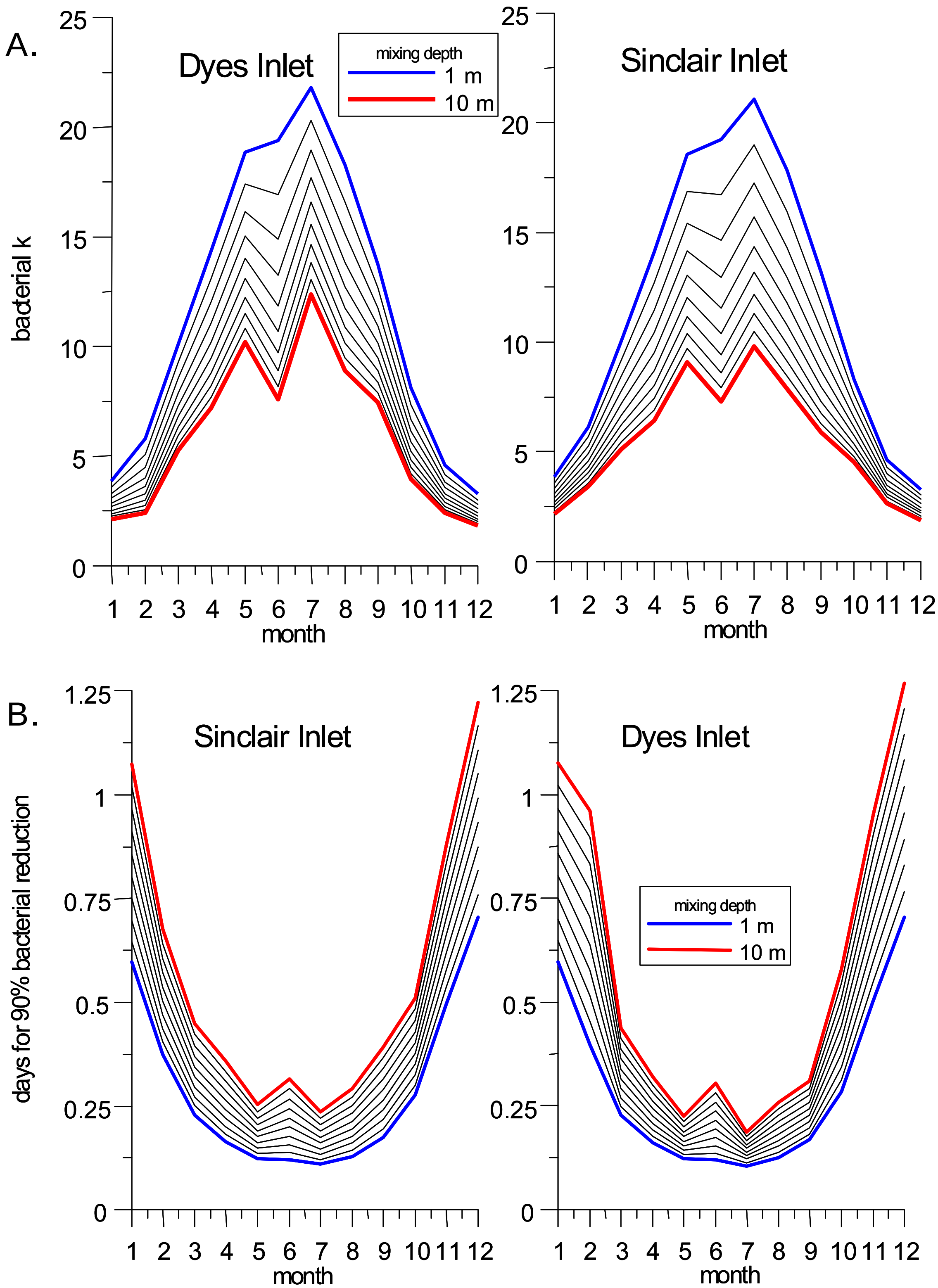


Figure 2-22. Seasonal variation of FC bacteria die-off rate (bacterial k) (A) and number of days required to reduce FC by 90% (B) in Sinclair and Dyes Inlets for depths of 1 to 10 meters (from Wang et al., 2005).

3. INTEGRATED MODELING OF FC LOADING AND FATE AND TRANSPORT IN SINCLAIR AND DYES INLETS

3.1 Integrated Model Linkage

We linked the integrated watershed-receiving water model by using output from HSPF, FC loading concentrations, and WWTP discharges as inputs to CH3D-FC. The time-varying flows produced by HSPF for each of the stream, stormwater, and shoreline pour points at 15-minute time steps were extracted from the HSPF Watershed Data Management (WDM) file. The data were reformatted and stored in an input file (File 13) to be read by CH3D-FC as time (DAY and HOUR), the (*i, j*) location in the model grid, and discharge in cfs (ft^3/s) for each cell representing a pour point. Since CH3D-FC ran with a 30- to 60-second time step, the model interpolated flow between the 15-minute flow hydrographs to simulate continuous freshwater flows (Salinity = 0) and FC load from the watershed. The FC load for each pour point ($PP_{Load(i,j)}$) was obtained by multiplying the varying flow ($Flow_{i,j}$) with the predefined FC concentration assigned to the pour point ($PPFC_{i,j}$):

$$PP_{Load(i,j)}\ [cfu/s] \quad = \quad PPFC_{i,j}\left[\frac{cfu}{100ml}\right]\times Flow_{i,j}\left[\frac{ft^3}{s}\right]\times\left[\frac{28316.8466\,ml}{ft^3}\right] \qquad [9]$$

Freshwater flow and FC loads from stream and stormwater watersheds were programmed to enter the CH3D-FC model grid at one pour point, while flows and loads from the shoreline watersheds were distributed into all the grids that were in contact with the shoreline (Figure 3-1). For example, the flow and load from watershed DSN100 were divided into nine inputs and distributed along the nine grids adjacent to the shoreline of the watershed (white arrows in Figure 3-1). The complete mapping file for all the pour points is available on the distribution CD or via the internet (Table 1-1).

The loads from the WWTPs were programmed to discharge into the surface grid nearest to the location of the WWTP outfall (Figure 3-2). This was necessary because CH3D is incapable of simulating the injection of mass at depth within the model grid, as this would violate the conservation of mass. The WWTPs discharge through diffusers on the bottom of the inlet. Under normal conditions, the buoyant plume from the discharges rises quickly to the surface and then spreads as a function of mixing and dispersion. Therefore, it was assumed that the loads from the WWTPs would enter the system through the surface grid cell nearest the plant. The initial dilution at the surface grid was similar to the mixing zone allowed in the discharge permits for the plants (Table 3-1) (Ecology, 2006a, b, 2007a).

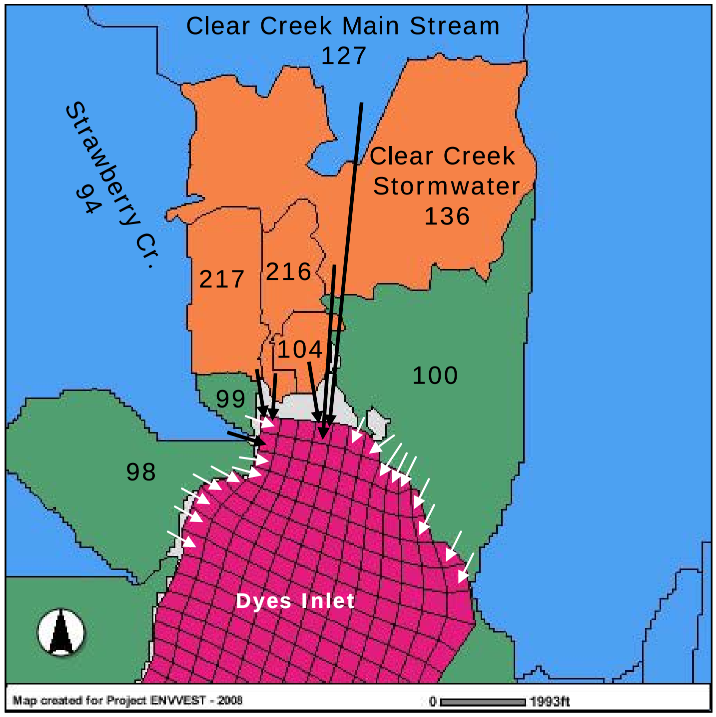


Figure 3-1. Example of linkage between CH3D-FC grids (red cells) and flows from streams (blue watersheds) and stormwater outfalls (orange watershed) shown by black arrows, and shoreline drainages (green watersheds) shown by white arrows.

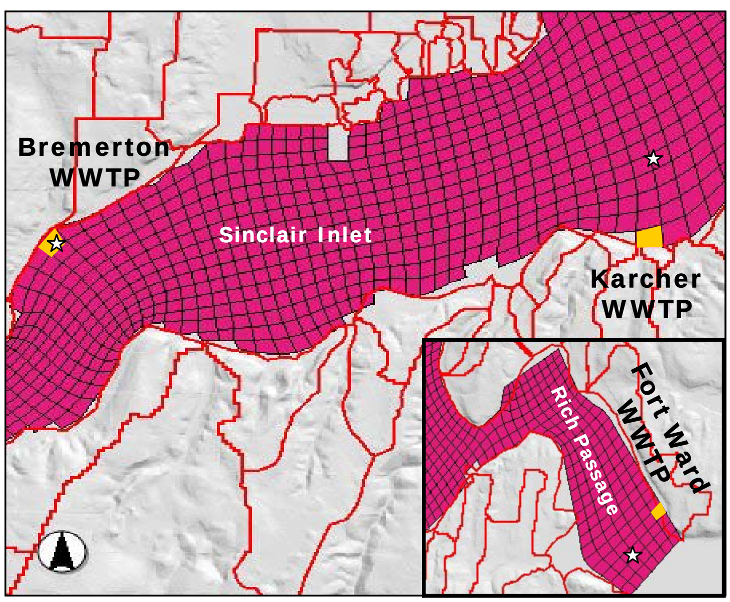


Figure 3-2. Location of the grid cells (yellow cells) receiving discharges from the Bremerton, Karcher Creek, and Fort Ward WWTPs (white stars mark approximate location of diffuser outfall).

Table 3-1. Comparison between permitted mixing zone and the CH3D model grid receiving discharges from the WWTPs.

	Permitted Chronic Mixing Zone					Modeled Mixing Zone					
	radius (ft)	area (ft^2)	depth (ft)[a]	dilution volume (ft^3)	dilution ratio	grid number (*i,j,z*)	area (ft^2)	avg depth (ft)	dilution vol (ft^3)	apparent dilution ratio	scaling factor[d]
Bremerton (Surface)	229	164,748	29	4,777,700	120:1	(*16,32,18*)	255,791	5.58 [b]	1,427,314	36:1	3.35
Bremerton (Depth Avg)	229	164,748	29	4,777,700	120:1	(*16,32,18*)	255,791	16.73 [c]	4,278,872	108:1	1.12
Karcher Creek	252	199,504	55	10,972,703	321:1	(*49,19,5*)	360,892	5.58 [b]	2,012,846	59:1	5.45
Fort Ward (Surface)	260	212,372	90	19,113,450	ns	(*90,6,77*)	409,675	5.58 [b]	2,284,933	ns	8.36
Fort Ward (Depth Avg)	260	212,372	90	19,113,450	ns	(*90,6,77*)	409,675	71.42 [c]	29,258,989	ns	0.65

ns = not specified

a Depth of outfall from permit

b Depth of surface grid (3.4 m) averaged over tidal cycle (1.7 m); grid location is shown in Figure 3-2

c Depth of surface and depth grids averaged over tidal cycle

d Factor required to equal permitted mixing zone

The grid cell used for the Bremerton WWTP discharge was very close to the actual discharge location; however, the grid cells used to simulate discharges from the Karcher Creek and Fort Ward WWTPs were located near the shore (Figure 3-2) while the diffusers extended out into the inlets at depth. It was assumed that the resulting FC levels in the receiving water from the modeled discharges would be more conservative (higher FC concentrations) because the model releases FC on the surface near the shore where the currents and mixing are less strong. Additionally, the WWTP discharges would combine with runoff from adjacent watersheds resulting in higher FC concentrations than if the discharges were further offshore.

Input files were prepared for all the time periods simulated. The HSPF model was run from 1 October 1 1992 to 30 September 2004, and a WDM file was generated with 15-minute flows for all the watersheds simulated in the model. For each specified simulation period, the flow data were extracted from the WDM file and formatted for input to CH3D-FC. Input files for CH3D-FC were also prepared for initial conditions, solar radiation, temperature, FC concentrations, and the boundary conditions. The data from individual storm events sampled in April, May, and October 2004, and monitoring data from WY2003, were used for model verification. WY2003 had the most observed data available, including samples that were collected during the wet season, dry season, as well as storm events (May et al., 2005). The rainfall collected from rain gauges for WY2003 ranged from 41-61 inches and was assumed to be typical for the study area (Figure 3-3). Suplemental information including the input files for each simulation period is available on the distribution CD or via the Internet (Table 1-1).

3.2 Integrated Model Verification

When the freshwater flows and FC loading were added into CH3D-FC, the model was run to make sure the flows from the watershed model were represented properly. Care was taken to match salinity with observed data, and this appeared to be sensitive to the initial conditions and boundary conditions, especially with respect to short term simulations of storm events (10 d). To better match the observed data near the mouth of Clear Creek in Northern Dyes Inlet, the lower subbasins of Clear Creek (DSNs 125, 130, 131, 133,129, 122, 134, 135, and 136) were reclassified as stormwater and stormwater FC loading concentrations were assigned to the simulated flows from those basins. Finally, the CH3D 91 x 96 grid was refined (94 x 105 grid) to increase resolution in selected areas to account for mixing in nearshore areas and areas with low currents to reduce the "initial dilution" effect of stream and outfall discharges (Figure 3-4). This was necessary because most of the observed data from WDOH and KCHD were taken in these nearshore areas where the shellfish beds are located. Suplemental information including the integrated model linkage is available on the distribution CD or via the internet (Table 1-1).

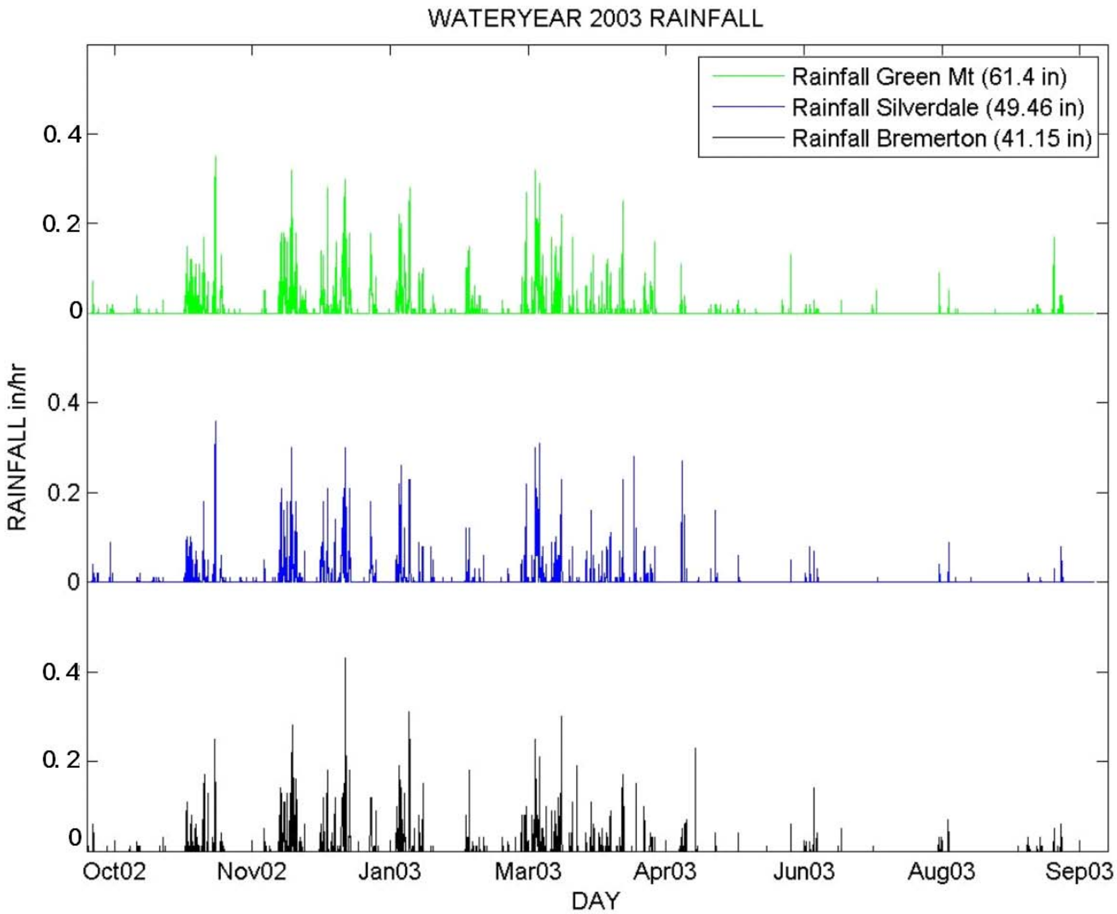


Figure 3-3. Rainfall data recorded for the study area for WY2003.

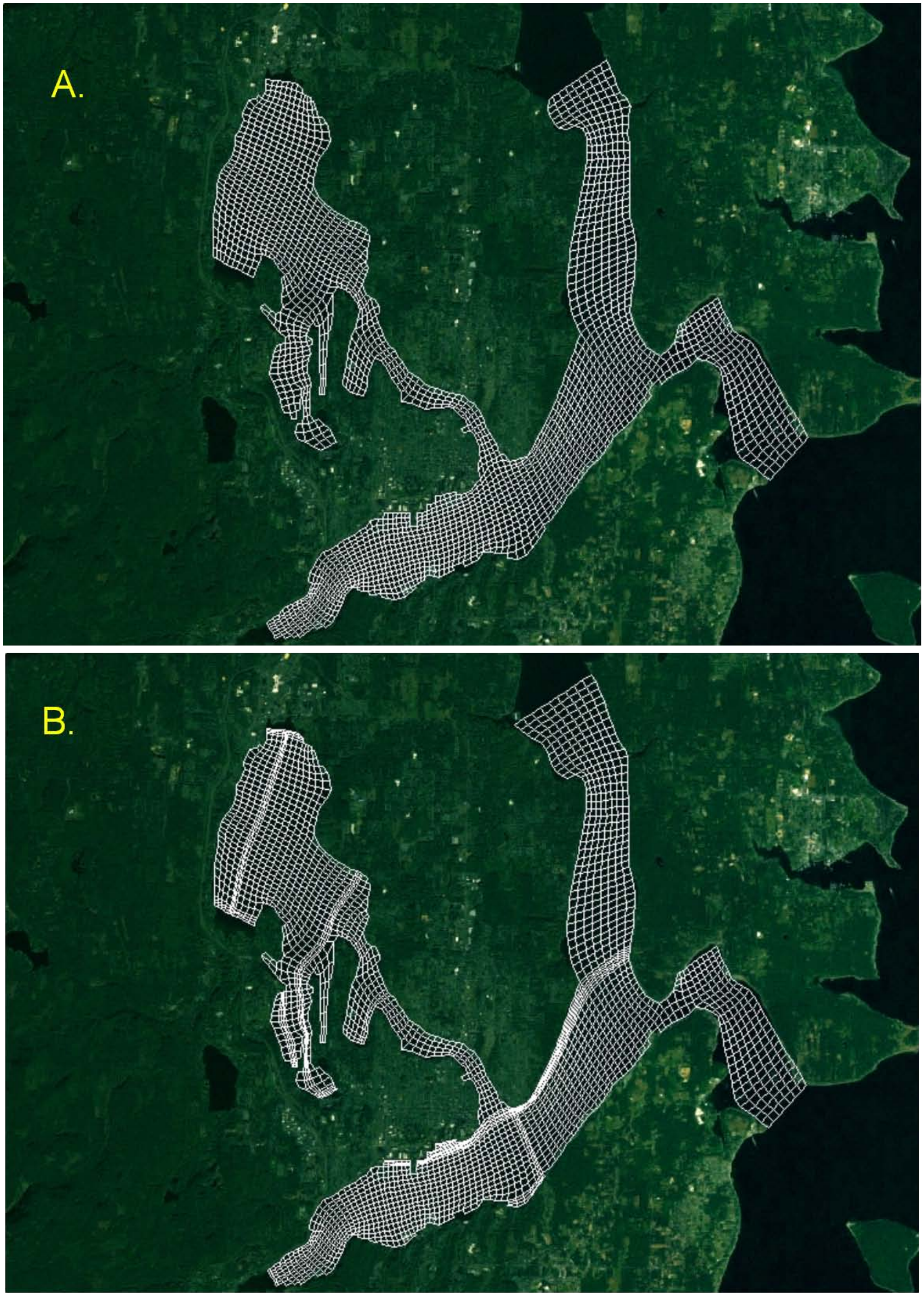


Figure 3-4. The computational grids used for CH3D-FC including the 91 x 96 grid (A) and the 94 x 105 grid (B) that has higher resolution in nearshore areas.

We used the observed FC data from streams and stormwater basins and the modeled flow from the watershed model to calculate the observed load and we compared the observed loads to the modeled loads to evaluate loading from the watershed. We then compared the observed FC data from the inlets to the CH3D-FC predictions to evaluate how well the model did in matching the observed data. The analysis also helped to identify sources of uncertainty and measure our confidence in the model predictions. No attempt was made to "fine-tune" the FC predictions because there was no way to know if the model was "wrong" or if additional sources were missing from the model. Under-prediction of FC concentrations where measured marine samples were higher may be due to additional sources that were not explicitly included in the model such as failing onsite sewage systems, wildlife, waterfowl, agricultural waste, and/or leaking sewer infrastructure. For example, from 2003 to 2005, five fecal pollution sources, four failing onsite sewage systems, and one raccoon latrine discharging into Chico Bay were found and corrected (KCHD, 2005), which may account for the higher observed data in Chico Bay. These intermittent sources are difficult to account for in the model and may be responsible for areas where the model underpredicted actual observed data. As pollution identification and correction projects are completed in the Dyes and Sinclair watersheds, the documentation of the sources found and corrections implemented may correlate well with these unexplained results.

There are uncertainties and limitations to what the model can simulate. The model indirectly accounts for sources from failed septic systems, leaking sewer infrastructure, and upland waterfowl and wildlife only to the extent that these sources contributed to the empirical data used to develop the FC loading concentration estimates (see Section 2.2). Potential sources of FC not in the model included marinas, recreational and commercial boating, broken pipes, CSO events, sediment resuspension, regeneration of bacteria spores, nearshore waterfowl, marine mammals, and any other unknown sources.

We evaluated how well the watershed model predicted FC loading from the streams and stormwater outfalls by comparing the observed load (*OL*) to the simulated load (*SL*). The simulated flow (*Sflow*) predicted by the HSPF model was used to calculate the *OL* and *SL*:

$$OL_{DSN,t}\,[cfu/hr] = OFC_{DSN,t}\left[\frac{cfu}{100ml}\right]\times Sflow_{DSN,t}\left[\frac{ft^3}{s}\right]\times\left[\frac{28316.8466\,ml}{ft^3}\right]\times\left[\frac{3600s}{hr}\right] \qquad [10]$$

$$SL_{DSN,t}\,[cfu/hr] = PFC_{DSN}\left[\frac{cfu}{100ml}\right]\times Sflow_{DSN,t}\left[\frac{ft^3}{s}\right]\times\left[\frac{28316.8466\,ml}{ft^3}\right]\times\left[\frac{3600s}{hr}\right] \qquad [11]$$

where

$OL_{DSN,t}$ = observed load for watershed *DSN* at time *t* in [*cfu/hr*]

$OFC_{DSN,t}$ = observed FC concentration for watershed *DSN* at time *t* [*cfu/100ml*]

$Sflow_{DSN,t}$ = simulated flow for watershed *DSN* at time *t* in cfs [ft^3/s]

$SL_{DSN,t}$ = simulated load for watershed *DSN* at time *t* in [*cfu/hr*]

$PFC_{DSN,t}$ = predicted geomean FC concentration for watershed *DSN* [*cfu/100ml*]

The data for WY2003 were used for this evaluation because it was the most comprehensive data set that covered the whole year, including storm events. The simulated flow was used to estimate the observed load because it was available for all watersheds for all time periods, and the modeled flow

was judged to be capable of simulating watershed-scale hydrology of the Sinclair and Dyes Inlets watershed with acceptable accuracy (see Section 2.1.4).

The observed and simulated mean, median, and mode of the FC loads were calculated for each watershed. The mean was used to evaluate the central tendency, the median evaluated the 50th percentile, and the mode represented the most frequent value of the observed and simulated data sets. The mean and median were compared by dividing the simulated mean and median by the observed statistic and scoring the result based on the criteria in Table 3-2. The scores were evaluated, and the final outcome was based on the lowest score obtained between the mean and median comparison (Table 3-3). For example, if the simulated mean and median were within a factor of two of the observed mean and median, the resulting outcome was EXCELLENT. If they were within a factor of five, the outcome was GOOD, and so forth. If there was a large discrepancy between the observed and simulated result, the comparison between the medians was used to determine whether the simulated result under- or overpredicted the observed data. Only the watersheds with five or more observations were used in the evaluation.

Table 3-2. Evaluation criteria used to score the difference between observed and simulated mean and median FC loads from the watershed.

Evaluation Criteria		
Factor	**Fraction**	**Score**
2	0.50	**Excellent**
5	0.20	**Good**
10	0.10	**Fair**
50	0.02	**Poor**
>50	<0.02	**Very Poor**

The results of the loading evaluation are tabulated in Table 3-3. Figures for all the watersheds are available on the distribution CD or via the internet (Table 1-1). An example of the results obtained for a stream, Chico Creek (DSN = 87), and a stormwater outfall, PSNS015 (DSN=167), are presented below.

Table 3-3. Comparison of observed and simulated FC loading (FC counts/hr) from watershed Data Set Numbers (DSNs) for streams and stormwater (SW) outfalls. The station id, number of samples (n), the observed and simulated mean, median, and mode, the evaluation scoring, and the outcome of the evaluation are tabulated for each stream and stormwater drainage area.

A. Observed and simulated statistics for streams ranked by simulated mean.

					Loading in fecal coliform counts/hr						Evaluation Score			
					Observed			Simulated			Simulated/Observed			
Type	StationID		DSN	n	mean	median	mode	mean	median	mode	mean		median	
Stream	CC01 (all)	ClearCC01	136	12	2.350E+09	5.264E+08	6.748E+07	1.788E+09	9.519E+08	6.020E+08	0.76	**Excellent**	1.81	**Excellent**
Stream	CC (upper)	ClearCC	127	32	8.120E+09	3.350E+08	2.635E+10	1.215E+09	7.140E+08	3.809E+08	0.15	Fair	2.13	Good
Stream	CH01	Chico	87	11	4.916E+08	2.213E+08	1.189E+06	1.102E+09	2.840E+08	9.373E+05	2.24	**Good**	1.28	**Excellent**
Stream	BJ01	Blackj	193	29	4.441E+09	8.337E+08	7.155E+07	7.994E+08	6.473E+08	4.039E+08	0.18	**Fair**	0.78	**Excellent**
Stream	KA01	Olney	64	38	8.645E+09	1.712E+09	2.370E+07	7.605E+08	5.805E+08	5.157E+08	0.09	Poor	0.34	**Good**
Stream	BA	Barker	58	48	3.826E+09	8.961E+08	7.519E+07	6.364E+08	3.558E+08	2.086E+08	0.17	**Fair**	0.40	**Good**
Stream	GC	Gorst	55	41	2.993E+09	1.344E+09	9.349E+07	5.642E+08	4.590E+08	2.368E+08	0.19	**Fair**	0.34	**Good**
Stream	SC	Straw	94	46	4.075E+09	4.580E+08	1.414E+08	3.663E+08	1.790E+08	3.408E+07	0.09	Poor	0.39	**Good**
Stream	MS01	Mosher	92	12	1.490E+07	8.270E+06	3.184E+05	2.076E+08	7.289E+07	3.155E+06	13.93	Poor	8.81	**Fair**
Stream	OB01	Ostrich	149	11	4.170E+08	2.153E+06	3.028E+05	2.048E+08	1.448E+06	1.609E+05	0.49	**Good**	0.67	**Excellent**
Stream	AN01	Ander	57	12	2.357E+08	1.097E+08	1.157E+07	1.970E+08	1.267E+08	8.754E+07	0.84	**Excellent**	1.16	**Excellent**
Stream	RS02	Ross	93	12	1.440E+08	3.138E+07	1.396E+06	1.025E+08	6.179E+07	4.010E+07	0.71	**Excellent**	1.97	**Excellent**
Stream	BI-SBC	Spring	210	5	2.870E+08	9.095E+07	6.854E+07	8.911E+07	6.162E+07	4.026E+07	0.31	**Good**	0.68	**Excellent**
Stream	ANNAP	Annap	187	31	4.477E+08	5.443E+07	6.468E+06	7.553E+07	5.794E+07	3.779E+07	0.17	**Fair**	1.06	**Excellent**
Stream	SACCO	Sacco	76	32	2.736E+08	4.088E+07	3.962E+05	5.352E+07	2.479E+07	1.856E+06	0.20	**Fair**	0.61	**Excellent**
Stream	PH01	Pharm	73	7	5.368E+07	1.232E+07	1.747E+06	3.059E+07	8.391E+06	4.379E+05	0.57	**Excellent**	0.68	**Excellent**
Stream	BE-LOW	Beaver	81	32	3.464E+08	1.021E+07	1.376E+04	3.030E+07	1.661E+06	7.211E+04	0.09	Poor	0.16	**Fair**
Stream	WC01	Wright	152	7	2.46E+06	1.66E+05	2.04E+04	2.92E+07	3.24E+05	6.04E+04	11.88	Poor	1.95	**Excellent**
Stream	IC01	Illahee	74	8	3.951E+07	9.272E+06	1.703E+06	2.751E+07	1.689E+07	8.156E+06	0.70	**Excellent**	1.82	**Excellent**
Stream	DE01	Dee	6	34	2.655E+08	2.037E+07	8.125E+06	2.751E+07	1.075E+07	5.664E+05	0.10	**Fair**	0.53	**Excellent**

Table 3-3 (continued).

B. Observed and simulated statistics for stormwater outfalls ranked by simulated mean.

					Loading in fecal coliform counts/hr						Evaluation Score				
					Observed			Simulated			Simulated/Observed				
Type	StationID		DSN	n	mean	median	mode	mean	median	mode	mean			median	
SW	LMK164	Loxie	154	16	4.347E+09	8.597E+07	3.119E+06	5.427E+08	5.213E+06	6.758E+05	0.12	**Fair**	Under	0.06	Poor
SW	B-ST01	LionsPk	7	15	3.541E+09	3.653E+08	1.537E+06	4.928E+08	1.361E+08	4.151E+06	0.14	**Fair**	Under	0.37	**Good**
SW	BI-FWSW	BIFortW	45	4	6.615E+09	3.400E+09	3.725E+08	3.714E+08	2.249E+08	1.099E+08	0.06		Under	0.07	
SW	B-ST28	Callow	158	10	4.984E+09	1.613E+08	4.893E+05	3.611E+08	2.413E+06	2.896E+05	0.07	Poor	Under	0.01	Very Poor
SW	BI-LCSW	BILynn	84	4	5.563E+08	2.357E+08	3.363E+07	3.273E+08	2.111E+08	1.155E+08	0.59		Under	0.90	
SW	LMK055	Tracyton	195	21	2.391E+08	5.562E+07	2.324E+06	3.126E+08	1.327E+08	8.495E+06	1.31	**Excellent**	Over	2.39	**Good**
SW	PSNS015	PSNS015	167	14	5.223E+09	2.520E+08	5.372E+04	3.098E+08	1.733E+07	1.738E+06	0.06	Poor	Under	0.07	Poor
SW	LMK001/002	KistapMall	216/217	20	2.083E+08	1.238E+08	5.709E+08	3.015E+08	2.357E+08	2.351E+08	1.45	**Excellent**	Over	1.90	**Excellent**
SW	PO-POBLVD	POBlvd	183	22	1.709E+09	1.532E+08	2.781E+07	2.674E+08	2.026E+08	1.251E+08	0.16	**Fair**	Under	1.32	**Excellent**
SW	B-ST04	B-ST04	11	11	3.219E+09	2.016E+08	3.681E+07	2.125E+08	4.170E+07	1.738E+06	0.07	Poor	Under	0.21	**Good**
SW	B-ST26	B-ST26	151	16	9.319E+08	1.698E+07	2.447E+04	1.800E+08	1.158E+06	1.931E+05	0.19	**Fair**	Under	0.07	Poor
SW	LMK020	LMK020	143	20	2.095E+09	5.209E+07	7.849E+04	1.754E+08	1.545E+06	1.931E+05	0.08	Poor	Under	0.03	Poor
SW	B-ST03	B-ST03	9	19	2.339E+08	6.541E+07	1.869E+06	1.548E+08	5.952E+07	3.379E+06	0.66	**Excellent**	Under	0.91	**Excellent**
SW	LMK026	LMK026	104	19	1.399E+08	5.833E+07	2.282E+08	1.497E+08	1.100E+08	9.815E+07	1.07	**Excellent**	Same	1.89	**Excellent**
SW	LMK002	LMK002	216	21	1.268E+08	3.254E+07	2.410E+06	1.461E+08	1.061E+08	9.692E+07	1.15	**Excellent**	Same	3.26	**Good**
SW	PSNS126	PSNS126	177	13	1.782E+10	5.026E+08	6.422E+03	1.284E+08	9.750E+06	5.792E+06	0.01	Very Poor	Under	0.02	Very Poor
SW	B-ST12	B-ST12	16	19	1.410E+08	9.379E+05	2.549E+04	8.296E+07	4.759E+07	8.592E+06	0.59	**Excellent**	Under	50.75	Very Poor
SW	LMK122	LMK122	215	20	2.614E+08	1.345E+07	2.356E+06	7.652E+07	5.218E+07	2.559E+07	0.29	**Good**	Under	3.88	**Good**
SW	B-ST27	B-ST27	162	10	5.585E+08	1.579E+08	2.658E+08	6.563E+07	1.583E+07	9.750E+06	0.12	**Fair**	Under	0.10	**Fair**
SW	LMK060	LMK060	199	21	4.457E+08	7.123E+07	2.608E+09	6.178E+07	2.593E+07	1.664E+06	0.14	**Fair**	Under	0.36	**Good**
SW	PO-BAYST	PO-BAYST	32	19	7.267E+08	7.785E+07	3.083E+05	5.401E+07	2.761E+07	1.863E+07	0.07	Poor	Under	0.35	**Good**
SW	PO-BETHEL	PO-BETHEL	202	11	3.481E+07	4.727E+06	1.815E+05	3.491E+07	2.259E+07	1.535E+07	1.00	**Excellent**	Same	4.78	**Good**
SW	PO-WILKENS	PO-WILKENS	31	20	4.824E+07	1.319E+07	1.289E+06	3.189E+07	2.669E+07	1.765E+07	0.66	**Excellent**	Under	2.02	**Good**
SW	PSNS081.1	PSNS081.1	169	13	1.419E+09	1.948E+08	4.261E+06	2.685E+07	5.792E+06	3.572E+06	0.02	Very Poor	Under	0.03	Poor
SW	PSNS008	PSNS008	166	12	1.102E+08	2.220E+07	1.019E+02	1.818E+07	1.931E+05	1.931E+05	0.16	**Fair**	Under	0.01	Very Poor
SW	LMK155	LMK155	38	17	3.202E+07	1.803E+07	1.964E+05	1.792E+07	8.180E+06	5.846E+05	0.56	**Excellent**	Under	0.45	**Good**
SW	LMK004	LMK004	99	21	2.809E+07	7.707E+06	1.784E+04	1.369E+07	2.993E+06	4.827E+05	0.49	**Good**	Under	0.39	**Good**
SW	LMK128	LMK128	27	23	1.224E+08	1.756E+07	1.755E+07	1.150E+07	4.153E+06	8.991E+05	0.09	Poor	Under	0.24	**Good**
SW	PSNS124	PSNS124	176	15	1.516E+07	1.623E+05	2.447E+03	8.966E+06	1.448E+06	1.545E+06	0.59	**Excellent**	Under	8.92	**Fair**
SW	PSNS082.5	PSNS082.5	170	3	3.982E+06	4.852E+06	1.713E+06	8.151E+06	1.255E+06	1.448E+06	2.05		Over	0.26	
SW	PSNS101	PSNS101	174	14	9.393E+07	8.104E+03	2.549E+03	3.549E+06	2.703E+06	1.738E+06	0.04	Poor	Under	333.53	Very Poor
SW	PSNS115.1	PSNS115.1	175	15	3.066E+07	2.141E+07	6.524E+03	3.275E+06	2.124E+06	1.352E+06	0.11	**Fair**	Under	0.10	Poor

Table 3-3 (continued).

C. Outcome of the evaluation of loading from streams.

					Evaluation Outcome			
Type	StationID		DSN	n	mean - median	DSN	Score	
Stream	CC01 (all)	ClearCC01	136	12	Excellent - Excellent	136	Excellent	
Stream	CC (upper)	ClearCC	127	32	Fair - Good	127	Fair	
Stream	CH01	Chico	87	11	Good - Excellent	87	Good	
Stream	BJ01	Blackj	193	29	Fair - Excellent	193	Fair	
Stream	KA01	Olney	64	38	Poor - Good	64	Poor	↓
Stream	BA	Barker	58	48	Fair - Good	58	Fair	
Stream	GC	Gorst	55	41	Fair - Good	55	Fair	
Stream	SC	Straw	94	46	Poor - Good	94	Poor	↓
Stream	MS01	Mosher	92	12	Poor - Fair	92	Poor	↑
Stream	OB01	Ostrich	149	11	Good - Excellent	149	Good	
Stream	AN01	Ander	57	12	Excellent - Excellent	57	Excellent	
Stream	RS02	Ross	93	12	Excellent - Excellent	93	Excellent	
Stream	BI-SBC	Spring	210	5	Good - Excellent	210	Good	
Stream	ANNAP	Annap	187	31	Fair - Excellent	187	Fair	
Stream	SACCO	Sacco	76	32	Fair - Excellent	76	Fair	
Stream	PH01	Pharm	73	7	Excellent - Excellent	73	Excellent	
Stream	BE-LOW	Beaver	81	32	Poor - Fair	81	Poor	↓
Stream	WC01	Wright	152	7	Poor - Excellent	152	Poor	↓
Stream	IC01	Illahee	74	8	Excellent - Excellent	74	Excellent	
Stream	DE01	Dee	6	34	Fair - Excellent	6	Fair	

Table 3-3 (continued).

D. Outcome of the evaluation of loading from stormwater outfalls.

					Evaluation Outcome			
Type	StationID		DSN	n	mean - median	DSN	Score	
SW	LMK164	Loxie	154	16	Fair - Poor	154	Poor	↓
SW	B-ST01	LionsPk	7	15	Fair - Good	7	Fair	
SW	BI-FWSW	BIFortW	45	4	-	45		
SW	B-ST28	Callow	158	10	Poor - Very Poor	158	Very Poor	↓
SW	BI-LCSW	BILynn	84	4	-	84		
SW	LMK055	Tracyton	195	21	Excellent - Good	195	Good	
SW	PSNS015	PSNS015	167	14	Poor - Poor	167	Poor	↓
SW	LMK001/002	KistapMall	216/217	20	Excellent - Excellent	217	Excellent	
SW	PO-POBLVD	POBlvd	183	22	Fair - Excellent	183	Fair	
SW	B-ST04	B-ST04	11	11	Poor - Good	11	Poor	↓
SW	B-ST26	B-ST26	151	16	Fair - Poor	151	Poor	↓
SW	LMK020	LMK020	143	20	Poor - Poor	143	Poor	↓
SW	B-ST03	B-ST03	9	19	Excellent - Excellent	9	Excellent	
SW	LMK026	LMK026	104	19	Excellent - Excellent	104	Excellent	
SW	LMK002	LMK002	216	21	Excellent - Good	216	Good	
SW	PSNS126	PSNS126	177	13	Very Poor - Very Poor	177	Very Poor	↓
SW	B-ST12	B-ST12	16	19	Excellent - Very Poor	16	Very Poor	↓
SW	LMK122	LMK122	215	20	Good - Good	215	Good	
SW	B-ST27	B-ST27	162	10	Fair - Fair	162	Fair	
SW	LMK060	LMK060	199	21	Fair - Good	199	Fair	
SW	PO-BAYST	PO-BAYST	32	19	Poor - Good	32	Poor	↓
SW	PO-BETHEL	PO-BETHEL	202	11	Excellent - Good	202	Good	
SW	PO-WILKENS	PO-WILKENS	31	20	Excellent - Good	31	Good	
SW	PSNS081.1	PSNS081.1	169	13	Very Poor - Poor	169	Very Poor	↓
SW	PSNS008	PSNS008	166	12	Fair - Very Poor	166	Very Poor	↓
SW	LMK155	LMK155	38	17	Excellent - Good	38	Good	
SW	LMK004	LMK004	99	21	Good - Good	99	Good	
SW	LMK128	LMK128	27	23	Poor - Good	27	Poor	↓
SW	PSNS124	PSNS124	176	15	Excellent - Fair	176	Fair	
SW	PSNS082.5	PSNS082.5	170	3	-	170		
SW	PSNS101	PSNS101	174	14	Poor - Very Poor	174	Very Poor	↓
SW	PSNS115.1	PSNS115.1	175	15	Fair - Poor	175	Poor	↓

The Chico Creek watershed constitutes the largest drainage area entering into the receiving waters of Sinclair and Dyes Inlets (Figure 3-5). Figure 3-6 shows the simulated and observed load for Chico Creek (DSN87) based on data collected at station CH01. The time series of the simulated (50th percentile) and observed load on arithmetic (Figure 3-6A) and log (Figure 3-6B) scales shows that the simulated load tracked the observed load relatively well with higher loading occurring during the wet winter months. The modeled FC concentration remained constant at 37 cfu/100 ml, in contrast to the observed concentration, which varied from 2 to 80 cfu/100 ml (Figure 3-6C). But since the load was driven by flow, the differences between simulated and observed load were relatively small (Figure 3-6D). The scatter plot of simulated versus observed load (Figure 3-6E) showed good agreement, and the frequency distribution obtained for both the observed and simulated data showed a similar pattern (Figure 3-6F). However, there were many more simulated data points (n = 8760, hourly for 365 days) than observed data points (n = 11). The simulated mean was 2.24 times higher than the observed mean and the simulated median was only 1.28 times higher than the observed median (Table 3-3A), resulting in a GOOD (GOOD–EXCELLENT) score for how well the loads from Chico Creek were predicted (Table 3-3A).

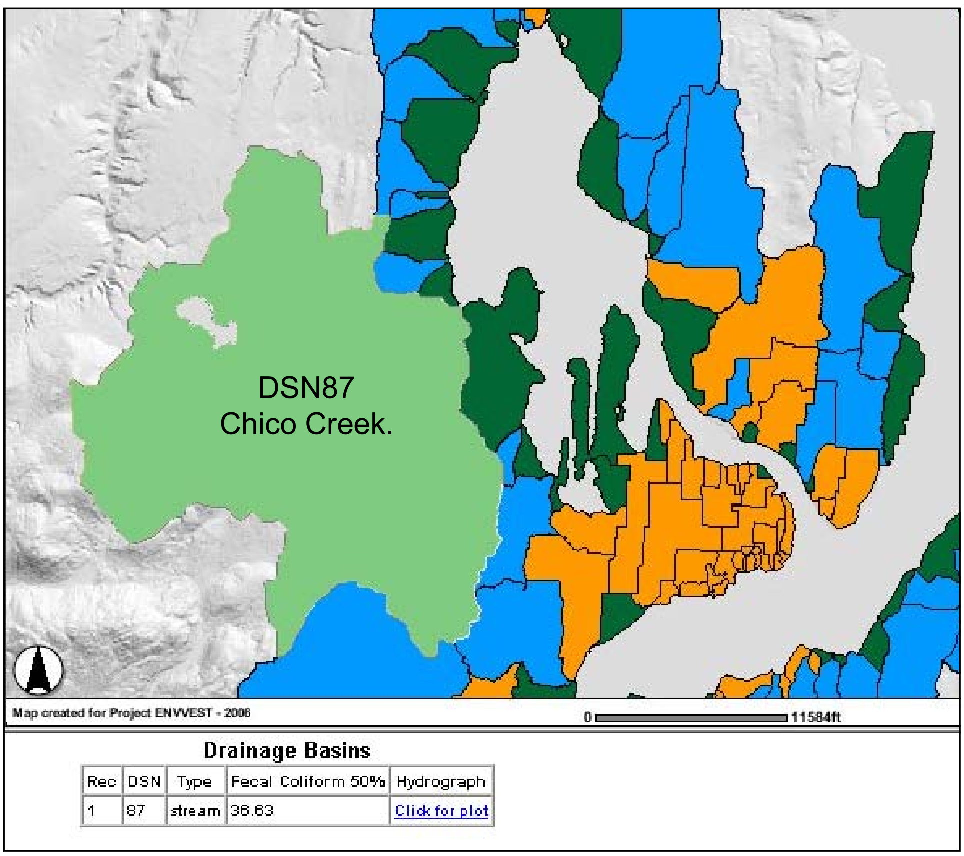


Figure 3-5. The Chico Creek drainage basin (DSN87).

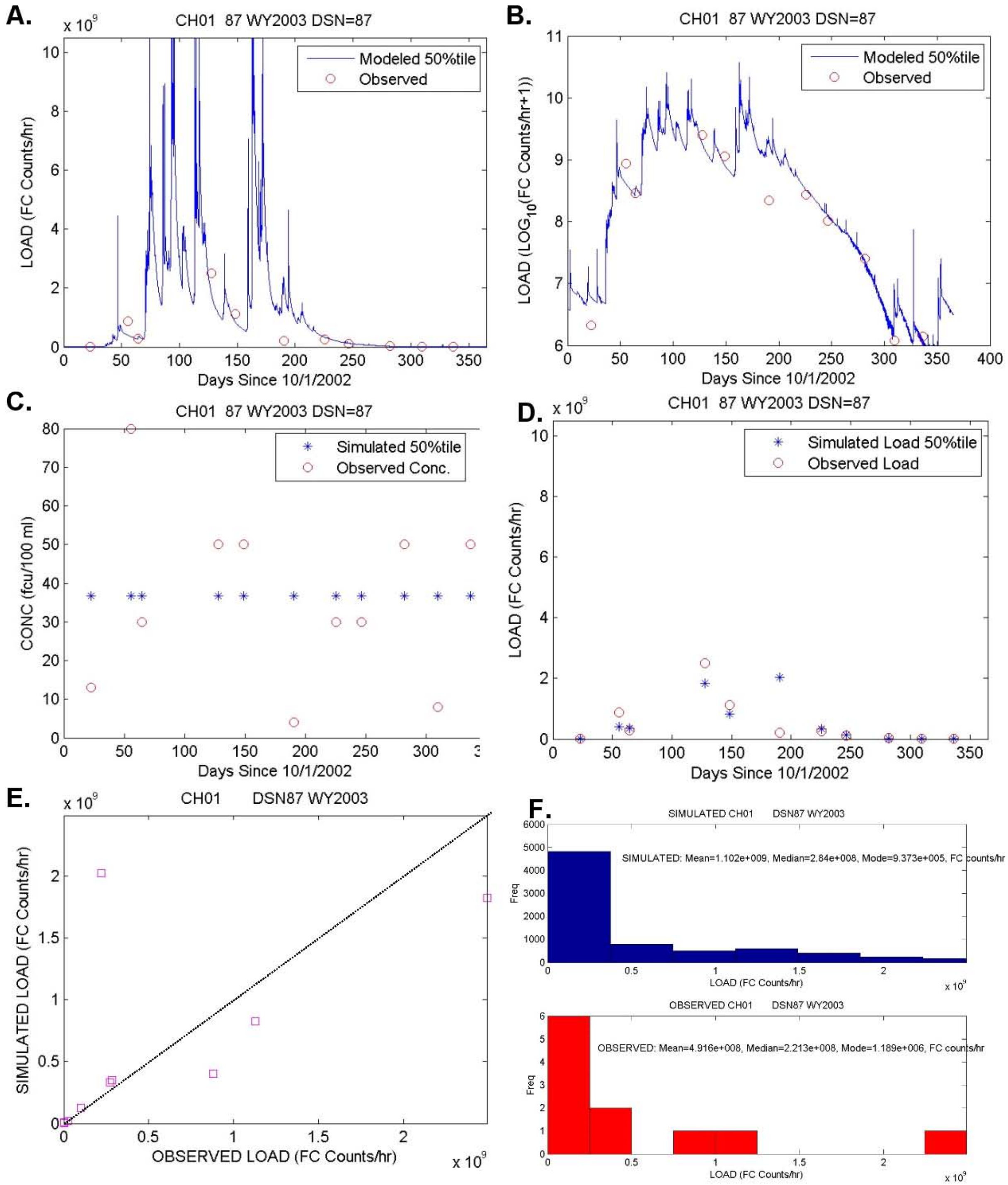


Figure 3-6. Plots of the simulated and observed load (FC counts per hour) for Chico Creek (DSN87) based on data collected at station CH01. Plots show time series of simulated (50th percentile) and observed load on arithmetic (A) and log (B) scales, simulated and observed concentrations (C), simulated and observed load (D), scatter plot of simulated versus observed load (E), and frequency histograms of the simulated and observed loads (F).

The stormwater basin PSNS015, which drains a large area of the Naval Station, including living quarters, ball fields, and commercial/industrial areas, was the largest drainage area from the Shipyard (Figure 3-7). The simulated and observed load for PSNS015 (DSN167) based on data collected at station PSNS015 is shown in Figure 3-8. The time series of the simulated (50th percentile) and observed load on arithmetic (Figure 3-8A) and log (Figure 3-8B) scales shows the wide variation and spikes of FC loads that are commonly associated with stormwater discharges. The simulated load tracked the observed load relatively well except for extreme spikes of high loading that occurred during storm events during the wet winter months. The modeled FC concentration remained constant at 947 cfu/100 ml, while the observed concentration varied from <100 to >12000 cfu/100 ml (Figure 3-8C). The differences between simulated and observed loads were within a factor of 10 to 100 (Figure 3-8D). The scatter plot of simulated versus observed load (Figure 3-8E) showed that the model tended to underpredict the FC loads coming from PSNS015, and the frequency plot showed a much different distribution for the simulated data than for the observed data (Figure 3-8F), partly because there were many more simulated data points (n = 8760, hourly for 365 days) than observed data points (n = 14). The simulated mean and median were within a factor of 17 and 15 of the observed mean and median, respectively (Table 3-3A), resulting in a POOR score for how well the loads from PSNS015 were predicted (Table 3-3D).

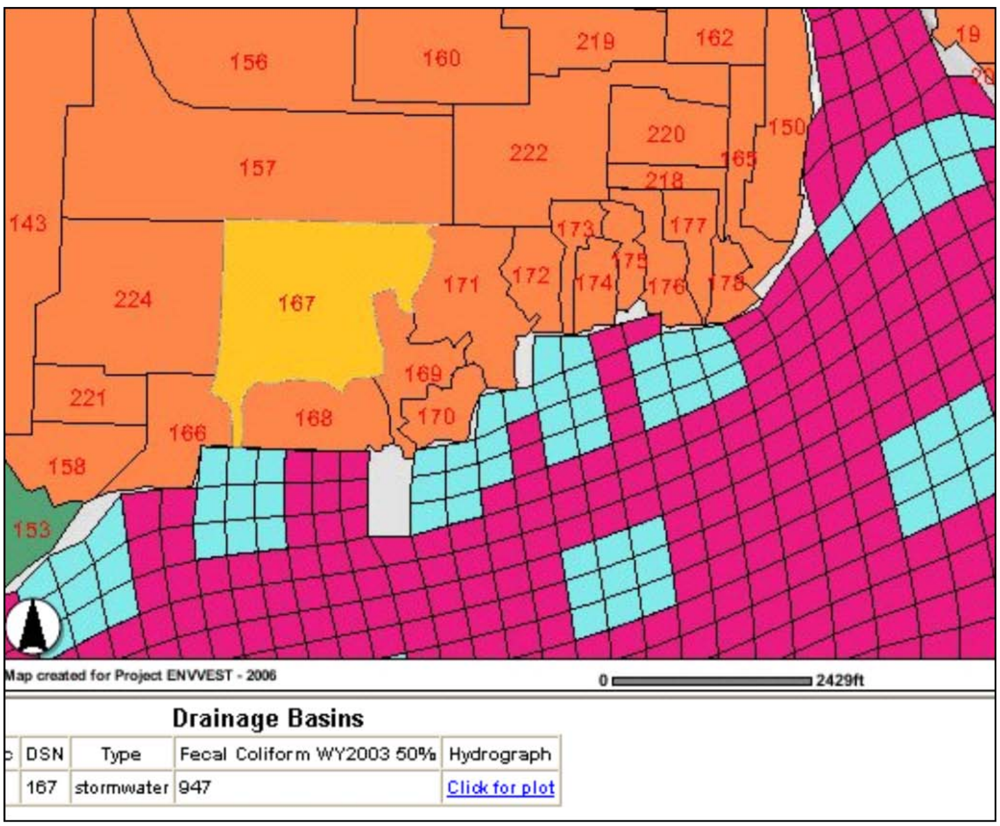


Figure 3-7. Drainage area for PSNS015 (DSN167) in Sinclair Inlet.

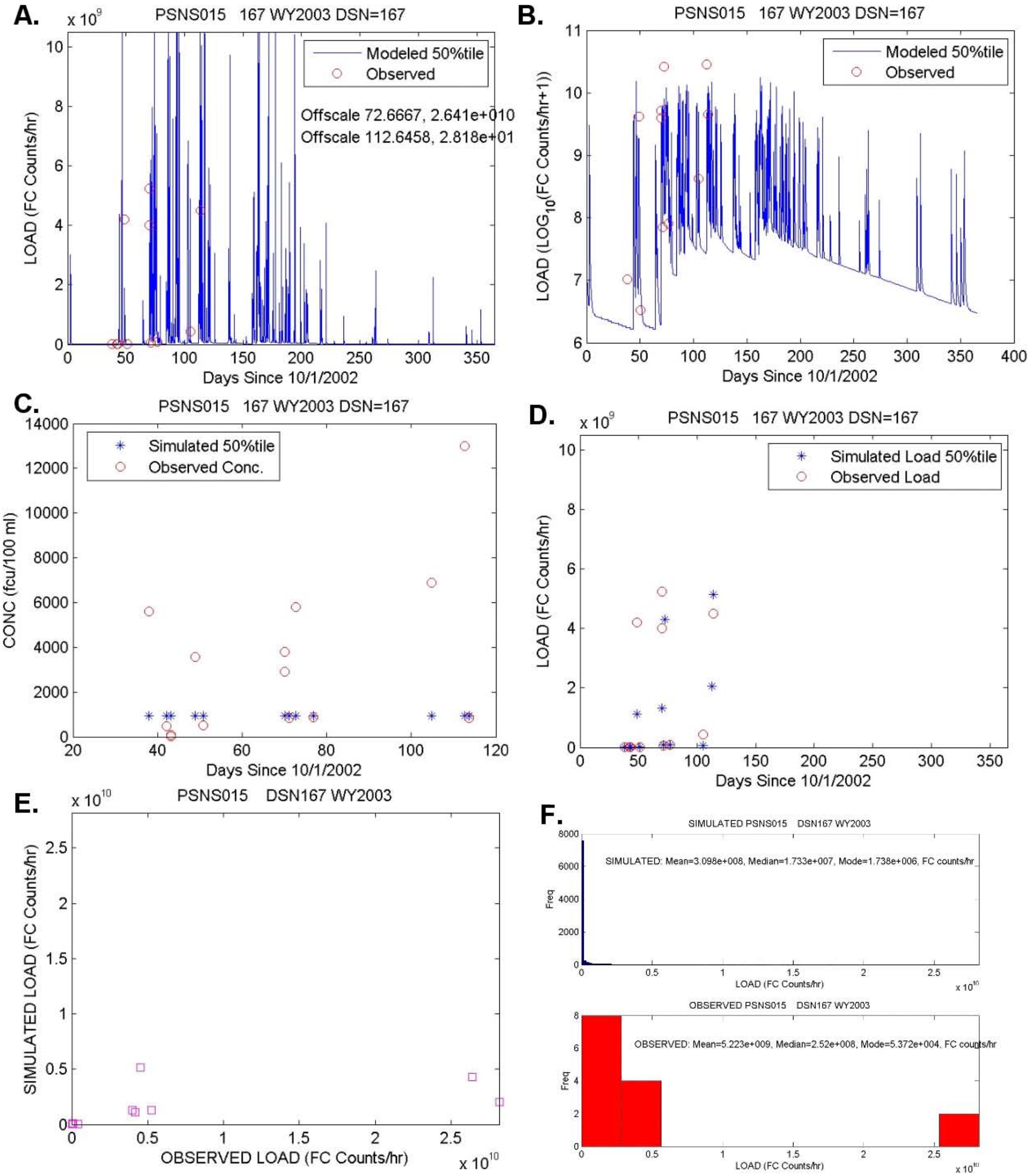


Figure 3-8. Plots of the simulated and observed load (FC counts/hr) for PSNS015 (DSN167) based on data collected at station PSNS015. Plots show time series of simulated (50th percentile) and observed load on arithmetic (A) and log (B) scales; simulated and observed concentrations (C); simulated and observed load (D); scatter plot of simulated versus observed load (E), and frequency histograms of the simulated and observed loads (F).

Overall, the model appeared to be better at predicting loads from streams than from stormwater outfalls (Table 3-3C,D; Figure 3-9). Most of the predicted loads from streams were scored as FAIR to EXCELLENT, especially the larger streams of Clear, Chico, Blackjack, Gorst, and Barker Creeks. The exceptions were streams that were rated POOR, including Olney (KA01), Strawberry (SC), Beaver (BE-LOW), Wright (WC01) Creeks, which underpredicted loads, and Mosher Creek (MS01), which overpredicted loads (Table 3-3C). No stream was rated VERY POOR, and simulated median FC loads from the streams were generally within an order of magnitude of the observed median FC loads.

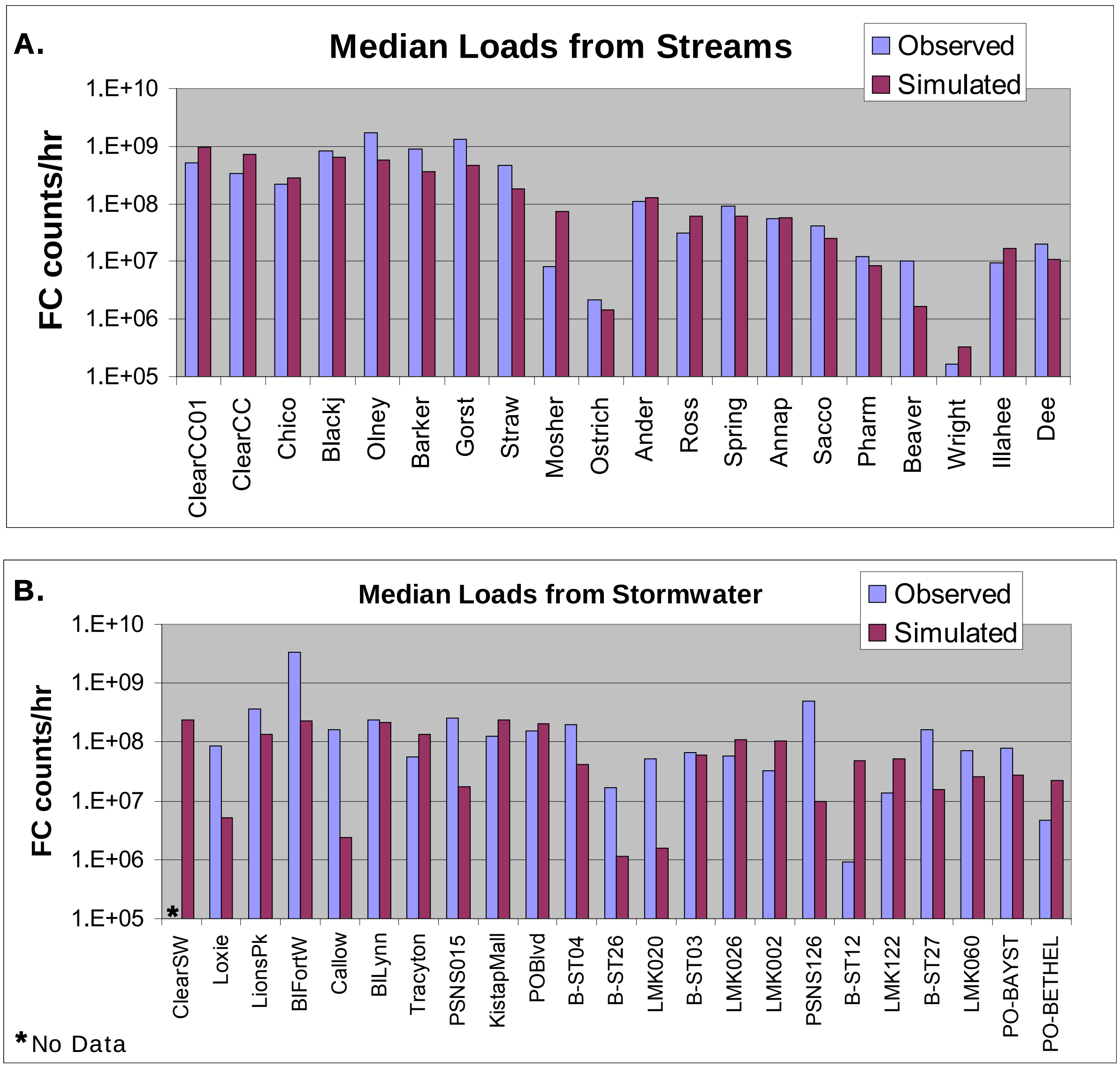


Figure 3-9. Comparison between observed and simulated median FC loads for WY2003 in streams (A) and stormwater outfalls (B). The median was based on all available data for observed and the modeled hourly loads over the year for simulated FC.

Of the 31 stormwater systems evaluated, 14 were scored as FAIR to EXCELLENT, eight were scored as POOR, six were VERY POOR, and three were not rated due to lack of data. The systems with POOR to VERY POOR scores tended to underpredict the FC loads (Table 3-3D), except for outfall BST-12, which overpredicted the median FC load by a factor of 50 (Table 3-3B). There were more discrepancies between the observed and simulated FC load for stormwater outfalls than for streams (Figure 3-9B).

The highest average annual loads were simulated for the major streams, especially Clear, Chico, Blackjack, Olney, Barker, and Gorst Creeks. The highest loads from the stormwater watersheds were obtained for Clear Creek (lower), Loxie Egans, BI Fort Ward, BI Lynwood Center, Tracyton Boat Dock, and PSNS015 (Figure 3-10). The highest monthly loads occurred during the wet months of December to March and lowest loads occurred during the low-flow summer months (Figure 3-11). Simulated loads from the Fort Ward and Bremerton WWTPs were the 18th and 27th highest sources, respectively, and the highest shoreline sources were BI Pleasant Beach (25th) and Erlands Point (31st) (Figure 3-10). Supplemental information is available on the distribution CD or via the internet (Table 1-1).

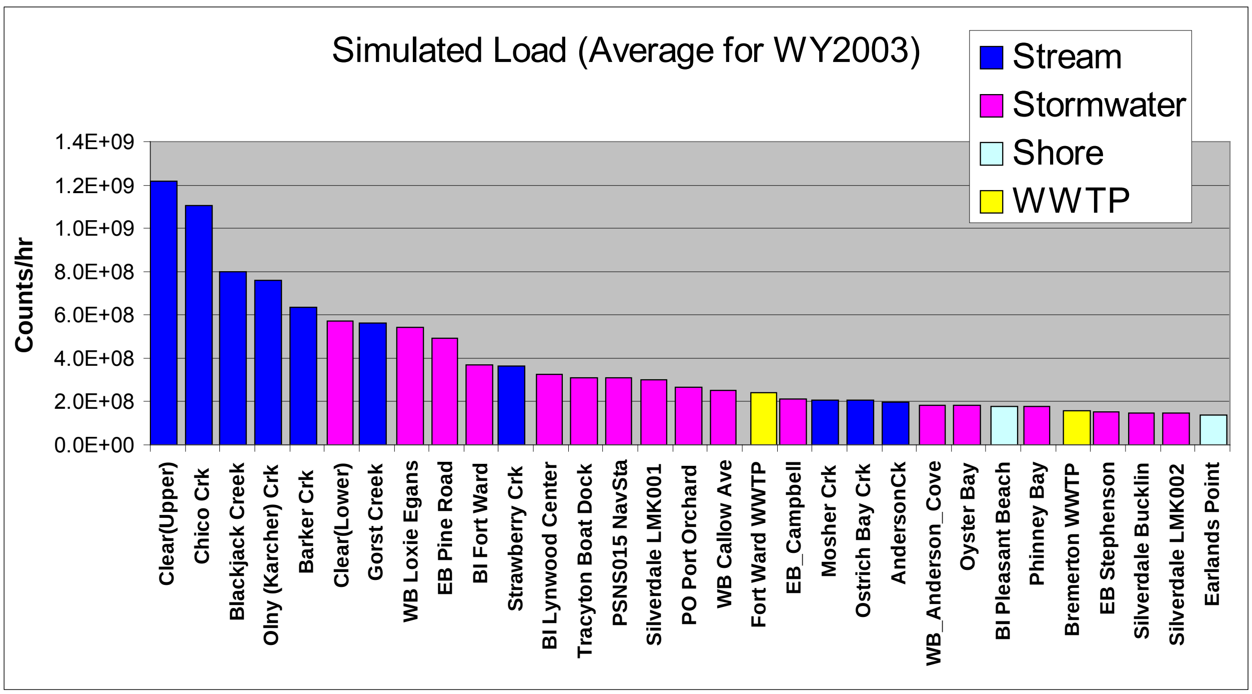


Figure 3-10. Simulated average yearly loads (counts/hr) for the top 31 sources of FC discharges into Sinclair and Dyes Inlets based on modeled hourly loads over the year. (Note that DMR data from the City of Bainbridge Island WWTP were inadvertently used for the Fort Ward WWTP.)

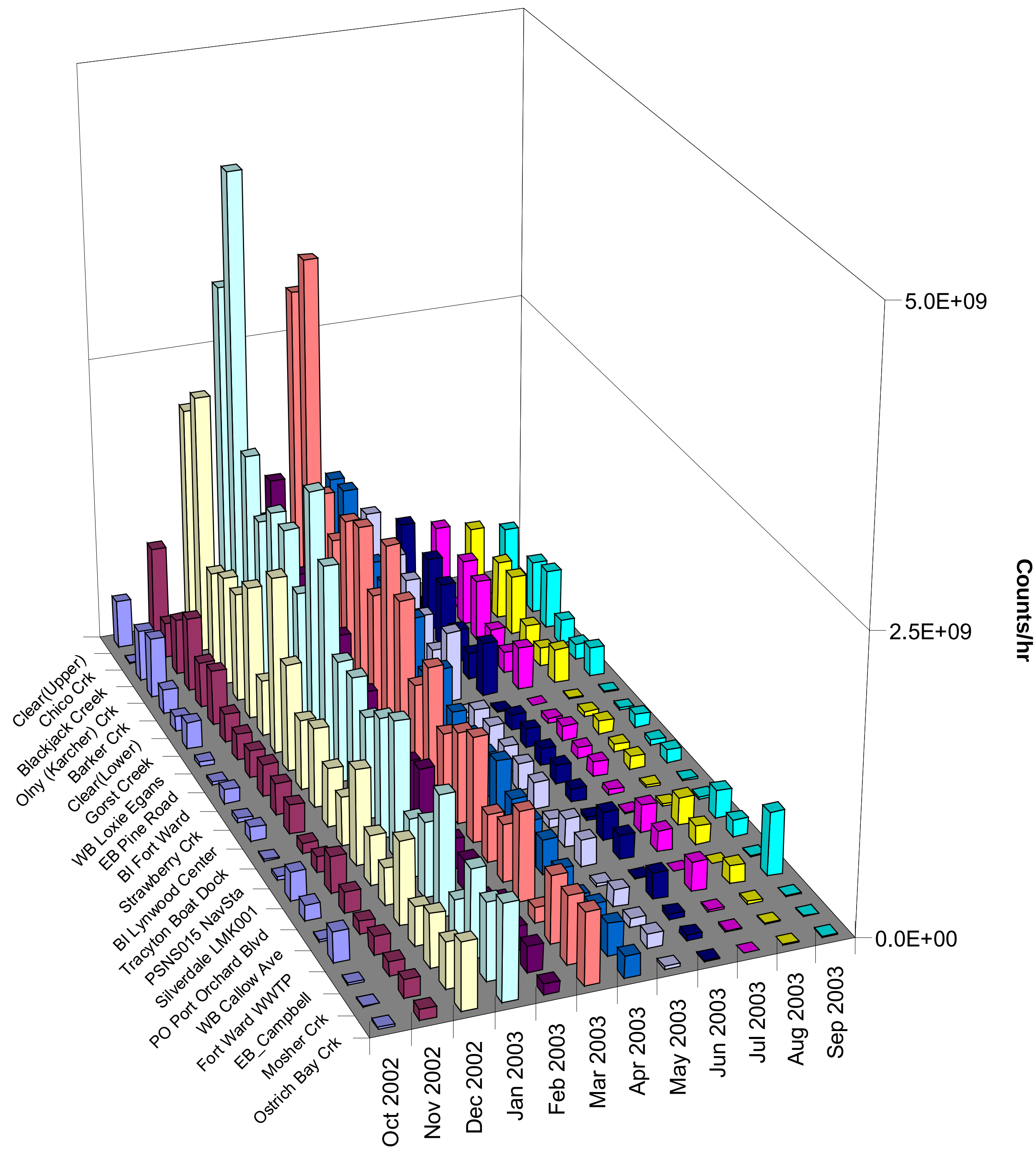


Figure 3-11. Average monthly fecal coliform loads by month of year (counts/hr) for the top 31 sources of FC discharge into Sinclair and Dyes Inlets based on modeled hourly loads for each month. (Note that DMR data from the City of Bainbridge Island WWTP were inadvertently used for the Fort Ward WWTP.)

The watershed loading evaluation showed that the major sources of FC in the inlets were well represented in the model. Most of the streams with POOR scores were from smaller basins with relatively lower loads (with the possible exception of Olney and Strawberry Creeks). The stormwater systems did not score as well as the streams, possibly due to the scarcity of data, the flashiness of the stormwater flows, and the high variability inherent in the observed data from the stormwater systems. The simulated results were based on the geomean FC loading concentration, so it is likely that a simulation of the 75th percentile would encompass the higher range of FC loading observed in the data. There is also uncertainty in comparing "discrete" values from the continuous simulation to observed grabs because slight variations in the timing of the sample could result in great differences in the apparent load, especially during storm events.

From the evaluation we concluded that there was a high degree of confidence for simulating watershed-wide FC sources into the receiving waters of the inlets. There was GOOD to EXCELLENT agreement with observed data for most watersheds; however, there was a tendency to underpredict loads in certain areas. While there was uncertainty in the simulated results (as discussed above), the model provided a consistent and reproducible means of simulating FC loading into the inlets. The evaluation criteria provided a means of appraising the accuracy of the model and assessing the confidence that could be placed on the model's predictions. Obviously, if there were major flaws in the loading estimates from the watershed, it would be very unlikely that CH3D-FC could produce useable results. Our confidence in predicting loading from the watershed also has a bearing on our confidence in predictions obtained from CH3D-FC (see below).

4. RESULTS OF SIMULATION SCENARIOS

4.1 Overview of CH3D-FC Simulations

We conducted series of simulations to verify model performance, identify critical conditions, assess model sensitivity and uncertainty, and calculate waste load and load allocations for the TMDL (Table 4-1). Model verification consisted of comparing model predictions to observed data collected during three storm events sampled in 2004 and observed data collected during WY2003. As explained above, CH3D-FC was set up to simulate individual storm events that occurred on 19 to 20 April 2004, 26 to 27 May 2004, 18 to 19 October 2004, and all of WY2003. For the 2004 storm events, ambient marine samples were collected 12 to 24 hours after the storm event (Johnston et al., 2004). Because of logistic constraints, ambient samples were collected from Northern Dyes Inlet for the April 2004 storm (Figure 4-1); from around Bremerton, including Oyster Bay, Ostrich Bay, Port Washington Narrows, and Sinclair Inlet, for the May 2004 storm (Figure 4-2); and from Port Orchard, Gorst, Sinclair Inlet, and the passages for the October 2004 storm (Figure 4-3). These data were compared to model output generated from recreating the storm events to determine how well the model performed.

We conducted sensitivity analysis to evaluate the sensitivity of model predictions to specific sets of input parameters, including FC loading concentration, stream and storm water flow, wind, and FC bacterial die-off. For the uncertainty analysis we assessed the effects of future growth and development on the amount FC bacteria that would be released into the inlets.

The WY2003 simulation was conducted to simulate FC loading over a yearly time cycle, determine the critical conditions for FC loading, compare to observed data collected over the year, and simulate scenarios required for the TMDL. We defined “canary nodes”, consisting of nine contiguous cells (Figure 4-4) at strategic locations within the model domain that coincided with locations of marine and nearshore monitoring stations and identified FC sources (Figure 4-5). Simulated data from the canary nodes were used to compare model output to observed data from sample locations and evaluate water quality standards. In locations where the sampling location was near the shoreline or along the curvilinear grid, the canary node was defined as the nine closest cells to the sample location. The canary nodes represented “coal mine canaries,” defined to be protective of water quality conditions at critical locations in the inlets for which observed data were also available (Figure 4-5).

CH3D uses a curvilinear grid that is represented by Cartesian rows and columns. The grid developed for Sinclair and Dyes Inlets contains 91 rows and 96 columns (91 x 96 grid) and a resolution of about 100 to 150 meters (300 to 450 feet, Figure 3-4A). A higher resolution grid was developed to reduce “initial” dilution in areas of low flushing such as the mouths of Clear, Chico, and Karcher Creeks, and other areas, including Oyster Bay, Ostrich Bay, Phinney Bay, and near the Shipyard. This higher resolution grid has 94 rows and 105 columns (94 x 105 grid) and a resolution of about 30 to 50 meters (100 to 150 feet) in those areas (Figure 3-4B). Simulations were conducted using both grids (Table 4-1).

Table 4-1. Summary of simulations completed.

#	Simulation	Watershed Hydrology	FC Loading	Grid	Purpose	Comment#
S1	April 19-20, 2004	1.00	25th Percentile	94 x 105*	Verification	Model Verification for Dyes Inlet Stations
S2	April 19-20, 2004	1.00	Geomean	94 x 105*	Verification	Model Verification for Dyes Inlet Stations
S3	April 19-20, 2004	1.00	75th Percentile	94 x 105*	Verification	Model Verification for Dyes Inlet Stations
S4	May 26-27, 2004	1.00	25th Percentile	94 x 105*	Verification & Sensitivity	**Low FC Loading** and Model Verification for Bremerton Stations
S5	May 26-27, 2004	1.00	Geomean	94 x 105*	Verification & Sensitivity	**Average FC Loading (Base Model)** and Model Verification for Bremerton Stations
S6	May 26-27, 2004	1.00	75th Percentile	94 x 105*	Verification & Sensitivity	**High FC Loading** and Model Verification for Bremerton Stations
S7	Oct 18-19, 2004	1.00	25th Percentile	94 x 105*	Verification	Model Verification for Port Orchard Stations
S8	Oct 18-19, 2004	1.00	Geomean	94 x 105*	Verification	Model Verification for Port Orchard Stations
S9	Oct 18-19, 2004	1.00	75th Percentile	94 x 105*	Verification	Model Verification for Port Orchard Stations
S10A	WY2003	1.00	Geomean	91 x 96	Verification	Comparison to field data for WY2003
S10B	WY2003	1.00	Geomean	94 x 105	Verification	Comparison to field data for WY2003
S11	WY2003	1.00	Geomean	91 x 96	Critical Conditions	Simulate actual conditions and assess compliance with marine water quality standards
S12	WY2003:100/200	1.00	100/200	91 x 96	Standard Part 1	Part 1: Streams and Stormwater set to 100 cfu/100ml; WWTP set to 200 cfu/100ml; Assess compliance in marine waters if freshwater sources meet 100/200 (Part I of the bacteria standard)
S13	WY2003:200/400	1.00	200/400	91 x 96	Standard Part 2	Part 2: Streams and Stormwater set to 200 cfu/100ml; WWTP set to 400 cfu/100ml; Assess compliance in marine inlets if freshwater sources meet 200/400 (Part II of the bacteria standard)

Table 4-1 (continued).

#	Simulation	Watershed Hydrology	FC Loading	Grid	Purpose	Comment[#]
S14	May 26-27, 2004	1.20	Geomean	94 x 105	Sensitivity	**May 2004 storm with modeled flows increased by 20%**
S15	May 26-27, 2004	2.00	Geomean	94 x 105	Sensitivity	**May 2004 storm with modeled flows increased by 100%**
S16	May 26-27, 2004	1.00	Geomean	94 x 105	Sensitivity	**May 2004 storm with constant wind: 10 m/sec (22.6 mph) from SW**
S17	May 26-27, 2004	1.00	Geomean	94 x 105	Sensitivity	**May 2004 storm with no FC Die-off (simulates conservative substance)**
S18	Future Build-Out – Expansive (Same)	N. Dyes Future Flow	N. Dyes Future Expansive Build-Out with Same Buffer	94 x 105	Future Conditions	**N. Dyes watersheds (Barker, Clear, Strawberry, Chico, LMK001, LMK002, BST01, and SBC) set to future flow and geomean FC loading with same buffer for expansive build-out development scenario**
S19	Future Build-Out – Expansive (Reduced)	N. Dyes Future Flow	N. Dyes Future Expansive Build-Out with Reduced Buffer	94 x 105	Future Conditions	**N. Dyes watersheds (Barker, Clear, Strawberry, Chico, LMK001, LMK002, BST01, and SBC) set to future flow and geomean FC loading with reduced buffer for expansive build-out development scenario**
S20	Future Build-Out – Expansive (Full)	N. Dyes Future Flow	N. Dyes Future Expansive Build-Out with Full Buffer	94 x 105	Future Conditions	**N. Dyes watersheds (Barker, Clear, Strawberry, Chico, LMK001, LMK002, BST01, and SBC) set to future flow and geomean FC loading with full buffer for expansive build-out development scenario**

* Results are also available for the 2004 storm events simulated with the 91x96 grid. Suplemental information including animations and time series plots for the simulations period are available on the distribution CD or via the internet (Table 1-1).
# Blue text denotes simulation results used for sensitivity analysis and brown text denotes simulation results used for uncertainty analysis

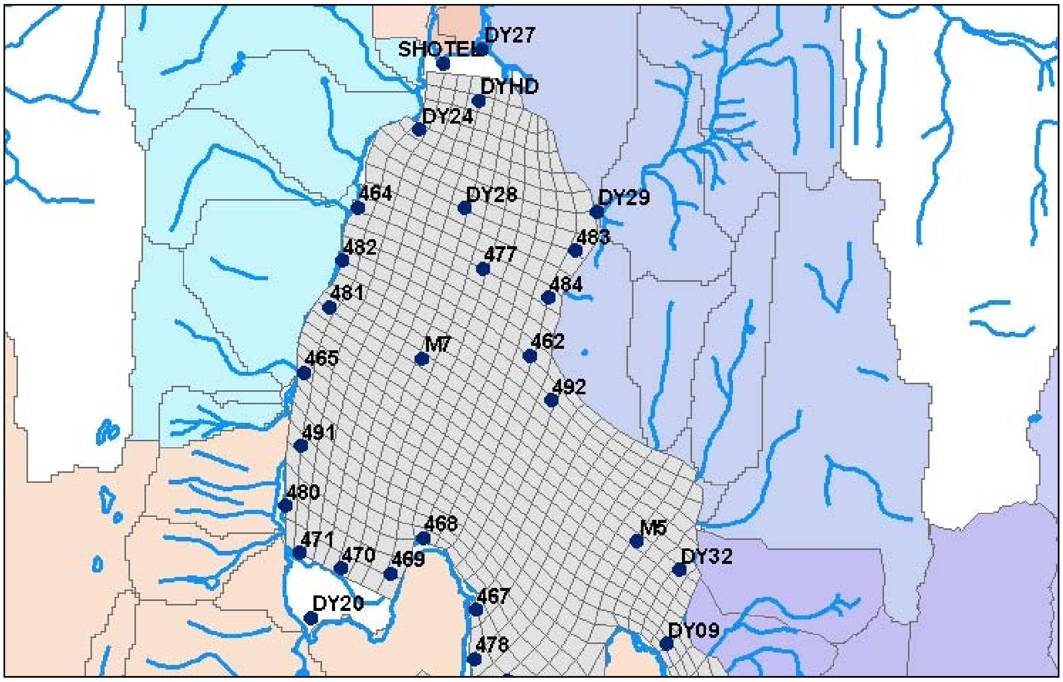


Figure 4-1. Location of stations in Northern Dyes Inlet sampled after the April 2004 storm event.

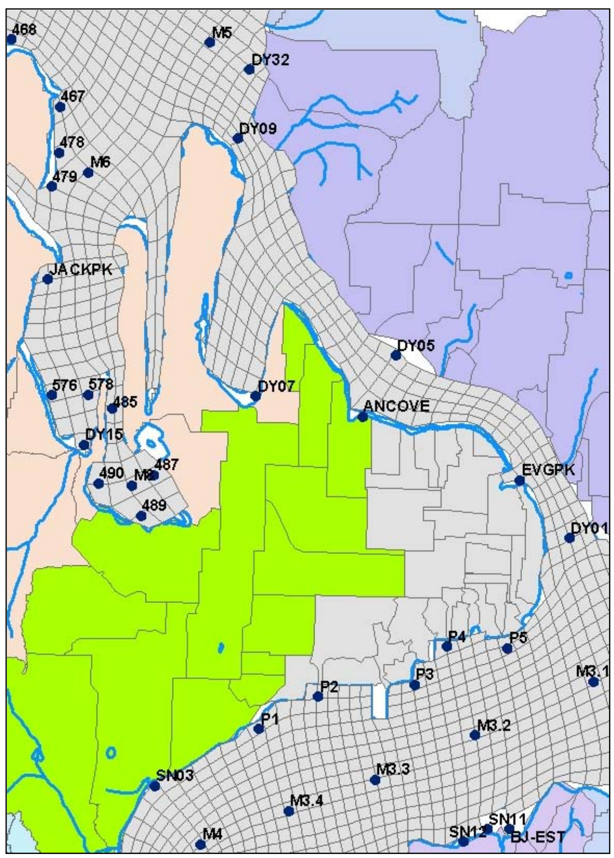


Figure 4-2. Location of stations around Bremerton, including Oyster Bay, Ostrich Bay, Port Washington Narrows, and Sinclair Inlet sampled after the May 2004 storm event.

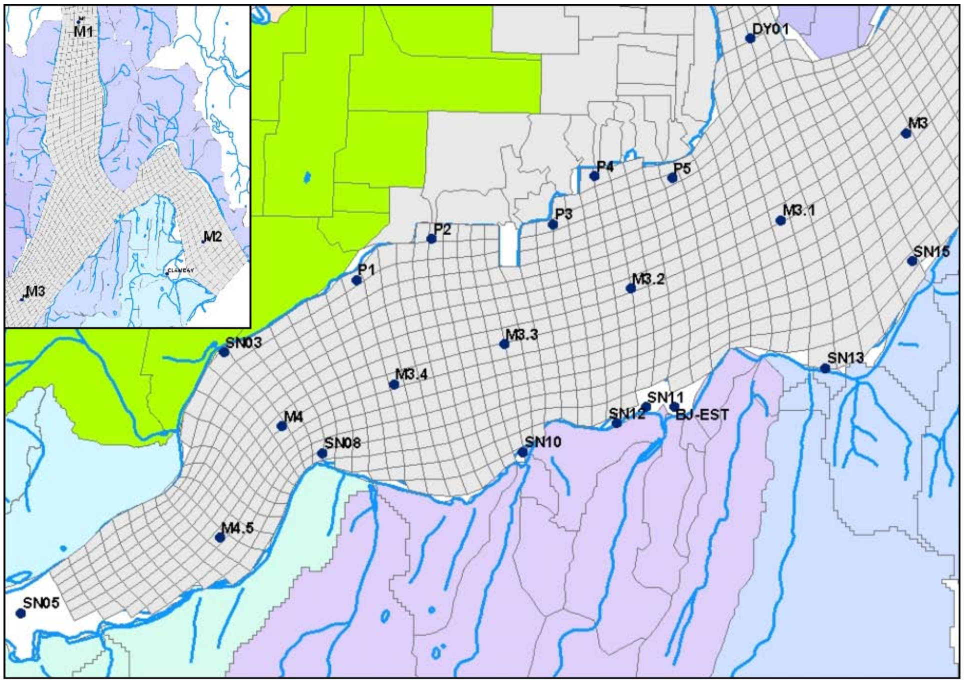


Figure 4-3. Location of stations near Port Orchard, Gorst, Sinclair Inlet, and passages (inset) sampled after the October 2004 storm event.

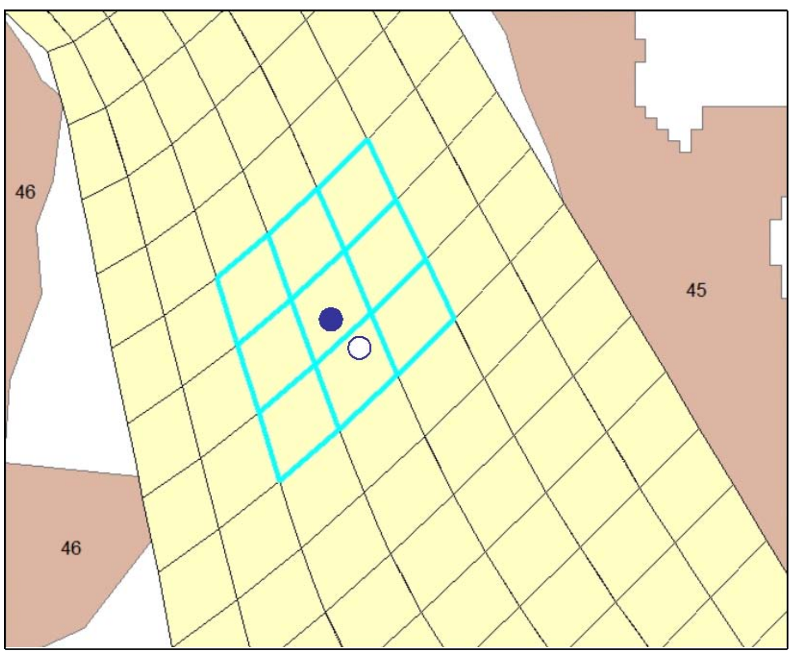


Figure 4-4. Diagram of a canary node (blue cells) that consists of nine contiguous cells surrounding the predetermined sample location (dark circle) and encompassing slight variations in actual sample locations (white circle).

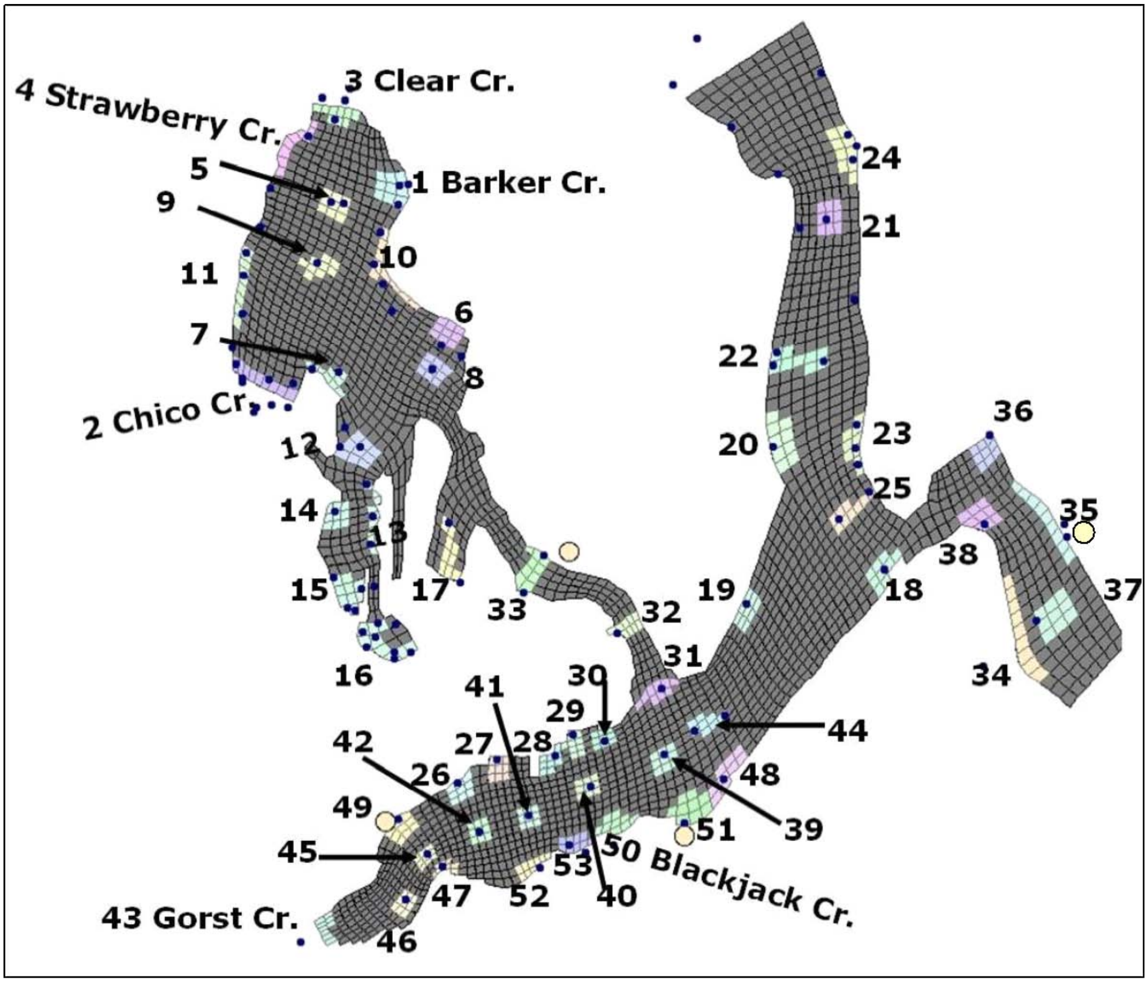


Figure 4-5. The number and location of canary nodes defined to compare model output to observed data from sample locations (blue dots) and water quality standards. Yellow circles represent locations of WWTP discharges.

4.2 2004 Storm Event Model Verification

We used simulations of storm events sampled in 2004 to evaluate model performance by comparing the output to field data (Simulations S1-S9, Table 4-1). The estuarine CH3D-FC model was run to simulate the tides, circulation conditions, fresh water, and FC inputs occurring during the sampling period starting from 8 days before the storm event and ending 24 hours after the storm event (10 d). CH3D-FC was used to simulate the 25,th 50th (geomean), and 75th percentile for the FC loading concentrations. The solar radiation and temperature were set according to each time period, and no wind forcing was used. The model output a time series of FC concentrations and salinities in each node for each of the loading concentrations simulated. The observed data (surface grabs) from each sampling station were compared to the simulated data from the corresponding (or nearest) surface model grid. The simulated and observed salinity at each station were also compared. A summary of the 2004 storm event model verification results are provided below. All the results from 2004 storm event verification analysis are available on the distribution CD or via the internet (Table 1-1).

The model results agreed well with observed data collected after each storm event for both nearshore and marine stations (Figure 4-6). The salinity levels simulated by the model were similar to observed values and agreed with expected mixing due to freshwater discharges during the storm events. The short-term (10 d) model predictions for salinity were found to be sensitive to the initial salinity conditions because longer simulations (> 30 d) of CH3D are generally required to reach a numerical salt balance.

The surface FC concentrations simulated by the model were very close to the observed grabs, especially for stations located in the middle of the inlets, for most of the nearshore area and for the 94 x 105 grid. However, for some of the nearshore stations near the mouths of creeks, the modeled results tended to underpredict FC concentrations. During the April 2004 event, the model underpredicted FC concentrations near the mouth of Clear Creek (DY27) and near the outfalls from LMK001/LMK002 (SHOTEL); see animations of the April 2004 simulations S1, S2, and S3 available on the distribution CD or via the internet (Table 1-1).

During the May 2004 event, the model showed very good agreement at 25 of the 31 stations sampled. At 8 of the 31 stations, FC concentrations were underpredicted: Ostrich Bay Creek (DY15), Oyster Bay shoreline (WDOH489 and WDOH487), Phinney Bay Creek (DY07), near the Bremerton WWTP outfall (SN03), and near stormwater outfalls within the Shipyard (P1, P2, and P5); see animations of the May 2004 simulations S4, S5, and S6 available on the distribution CD or via the internet (Table 1-1).

The FC concentrations predicted for the October 2004 event were very similar to the observed FC concentrations, including the stations near the Shipyard (P1, P2, P3, P4, and P5), samples taken at the surface and at depth at the boundary stations (M1 and M2), and in the middle of Sinclair Inlet (M3.3). Most of the stations in Sinclair Inlet were elevated due to the major release of bacteria from the upset conditions at the Karcher Creek WWTP that occurred during the storm (Table 2-12).[12] While the model could adequately capture the plume of FC from the Karcher Creek WWTP, the model underpredicted the FC levels for the mouth of Gorst Creek (SN05), the head of Sinclair Inlet (M4.5), and the Port Orchard waterfront (SN12), suggesting that additional local FC sources were present in those areas that were not accounted for in the model. See animations of the Oct 2004 simulations S7, S8, and S9 available on the distribution CD or via the internet (Table 1-1).

The simulation results of the 2004 storm events showed that the integrated model could produce plausible results with relatively high accuracy for major portions of the model domain. While there were mismatches between model predictions and observations at some locations, the integrated model appeared to be quite capable of simulating storm runoff and FC loading during storm events.

[12] Lance Hunt, Karcher Creek WWTP, personal communication.

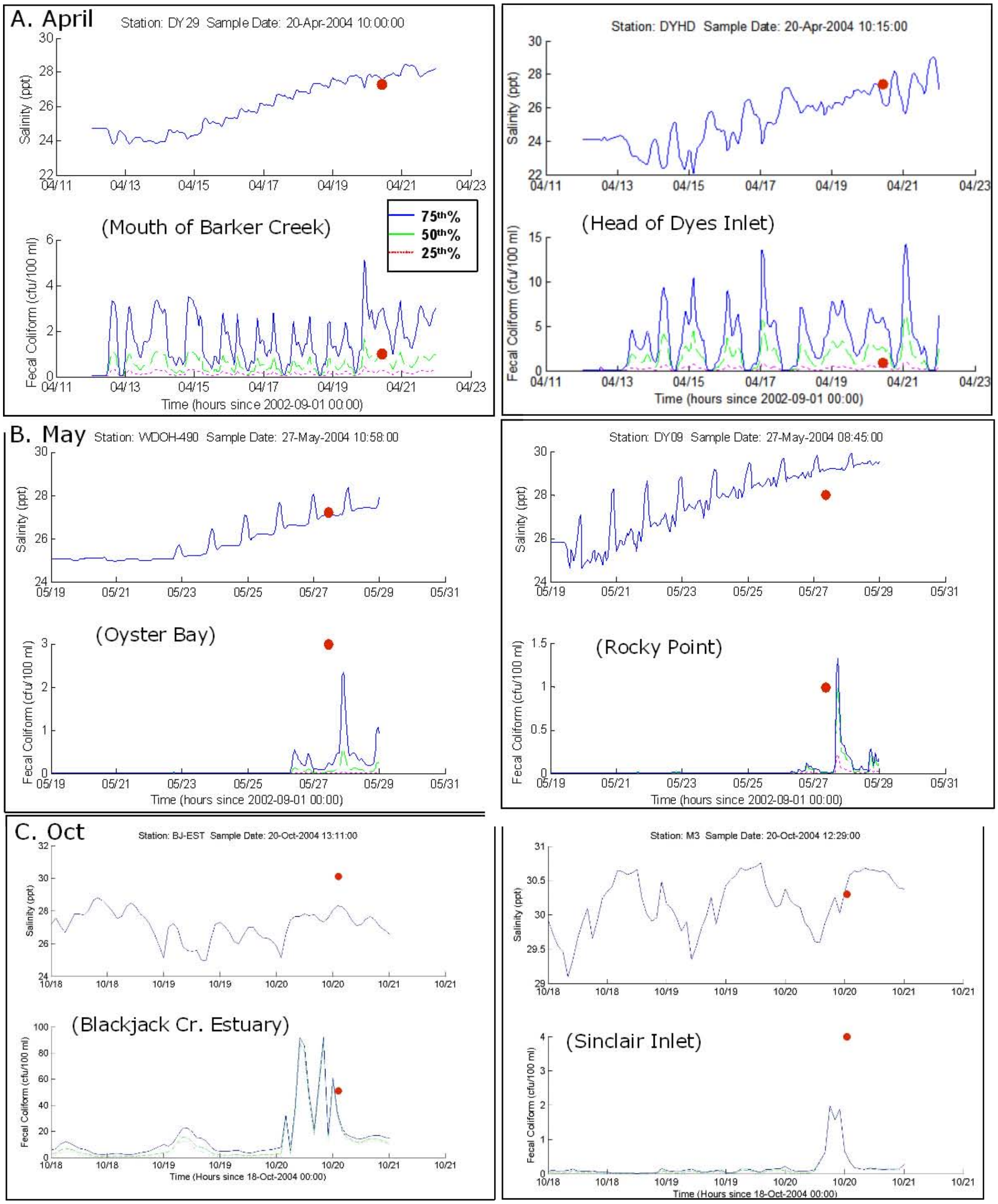


Figure 4-6. Example results from comparison between simulated (lines) and observed data (red points) for salinity and FC from the April (A), May (B), and October (C) 2004 storm events for nearshore (left panels) and marine (right panels) stations. Simulated results for the 25,th 50th- (geomean), and 75th percentiles of the FC loading concentrations are shown in red, green, and blue, respectively.

4.3 WY2003 Simulations

Simulations of FC loading for Water Year 2003 (1 October 2002 to 30 September 2003) were conducted to simulate FC loading over the whole year (Simulations S10A, S10B, and S11). The estuarine CH3D-FC model was run to simulate the tides, circulation conditions, fresh water, and FC inputs occurring during WY2003. The model was started 30 days before freshwater flows and FC inputs entered the model on 1 October 2002 and ended on 30 September 2003 (395 days, with FC loading beginning on day 30). The 30-day "warm-up" period was completed to allow CH3D-FC to reach dynamic equilibrium with the salt balance before freshwater flows were turned on. The load was based on the 50th percentile (geomean) for the FC loading concentrations, the solar radiation and temperature varied for each month, and no wind forcing was used. The model output time series of FC concentrations and salinities in each node over WY2003.

Output from the model was used to compare to observed data and identify critical conditions, the conditions most likely to result in exceeding water quality standards. An example of simulation results is shown in Figure 4-7. This grid cell at the mouth of Clear Creek shows the fluctuation of FC concentrations as a function of storm intensity (rainfall), solar radiation (KWh/m^2), and tide height (m). The simulation results showed that FC concentrations were driven by storm event runoff, die-off due to solar radiation, and tidal mixing. The maximum concentrations occurred after darkness during weak tides following runoff from storm events (Figure 4-7). The wet winter months with higher runoff due to storm events and lower solar radiation resulted in the highest FC concentrations throughout the year, although water quality criteria were also exceeded during the summer months.

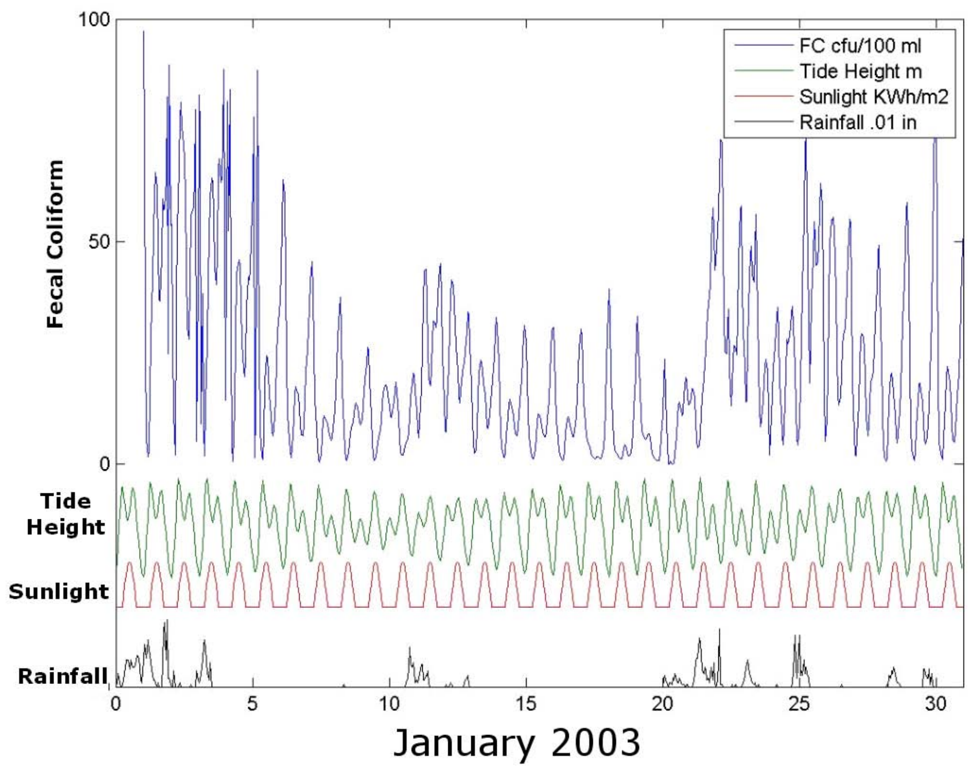


Figure 4-7. Example of simulation results for the grid cell at the mouth of Clear Creek showing the fluctuation of FC concentrations as a function of storm intensity (rainfall), solar radiation (KWh/m^2), and tide height (meters).

4.4 WY2003 Verification

The observed data derived from sampling were compared to the simulated data from the corresponding canary nodes (Figure 4-5) to evaluate how well the model performed. Preliminary results using the 91 x 94 grid were found to underestimate FC concentrations in some nearshore locations due to the initial dilution that was too rapid for the currents and mixing at the point of discharge. Therefore, a higher resolution grid 94 x 105 was developed to reduce the effects of initial dilution in those areas. An example of the model's configuration for the Gorst Creek and Clear Creek canary nodes is shown in Figure 4-8. All the results for the WY2003 verification are available on the distribution CD or via the internet (Table 1-1).

4.4.1 S10A: WY2003 Using 91 x 96 Grid

All streams, stormwater outfalls, and WWTPs were set to "actual conditions" to simulate total FC loading from all sources for Water Year 2003, 1 October 2002 to 30 September 30 2003 (WY2003). Model output was compared to observed data. The results for simulation S10A are available on the distribution CD or via the internet (Table 1-1).

4.4.2 S10B: WY2003 Using 94 x 105 Grid

A higher resolution grid was developed to reduce initial dilution in areas of low flushing such as the mouths of Clear, Chico, Karcher Creeks, and other areas, including Oyster Bay, Ostrich Bay, Phinney Bay; and near the Shipyard. All streams, stormwater outfalls, and WWTPs were set to "actual conditions" to simulate total FC loading from all sources for WY2003. Model output was compared to observed data. The results for simulation S10B are available on the distribution CD or via the internet (Table 1-1).

4.4.3 Verification Results

We compared the simulated results for each of the canary nodes to the observed data collected from within the canary nodes during WY2003. The observed data were marine and nearshore samples collected by ENVVEST, KCHD, and WDOH sampling teams during the simulation period, 1 October 2002 to 30 September 2003. For each group of nine nodes, the time series of simulated FC concentrations (colored lines) and observed FC measurements (red circles) were displayed (cfu/100 ml). The water quality limits for the shellfish harvesting bacteria criteria of 14 cfu/100 ml (geometric mean) and 43 cfu/100 ml (ninety percentile) were also displayed (Figure 4-9A). Scatter plots of the observed versus predicted data points (Figure 4-9B) and cumulative distribution plots of the observed and modeled data (Figure 4-9C) were generated for each canary node to visualize the differences between the model predictions and observed data. All the model plots are available on the distribution CD or via the internet (Table 1-1).

The frequency of exceeding Part I (14 cfu/100 ml) or Part II (43 cfu/100 ml) of the standard was calculated for the observed (*OBS*) and simulated (*SIM*) data from each canary node ($_{CN}$):

$$OBSFreq14_{CN} = \text{For } i{=}1,n;\ \text{if } OBS_i > 14;\ j{=}j{+}1;\ \text{end};\ j/n\times 100 \quad [12]$$

$$OBSFreq43_{CN} = \text{For } i{=}1,n;\ \text{if } OBS_i > 43;\ k{=}k{+}1;\ \text{end};\ k/n\times 100 \quad [13]$$

$$SIMFreq14_{CN} = \text{For } i{=}1,m;\ \text{if } SIM_i > 14;\ j{=}j{+}1;\ \text{end};\ j/m\times 100 \quad [14]$$

$$SIMFreq43_{CN} = \text{For } i{=}1,m;\ \text{if } SIM_i > 43;\ k{=}k{+}1;\ \text{end};\ k/m\times 100 \quad [15]$$

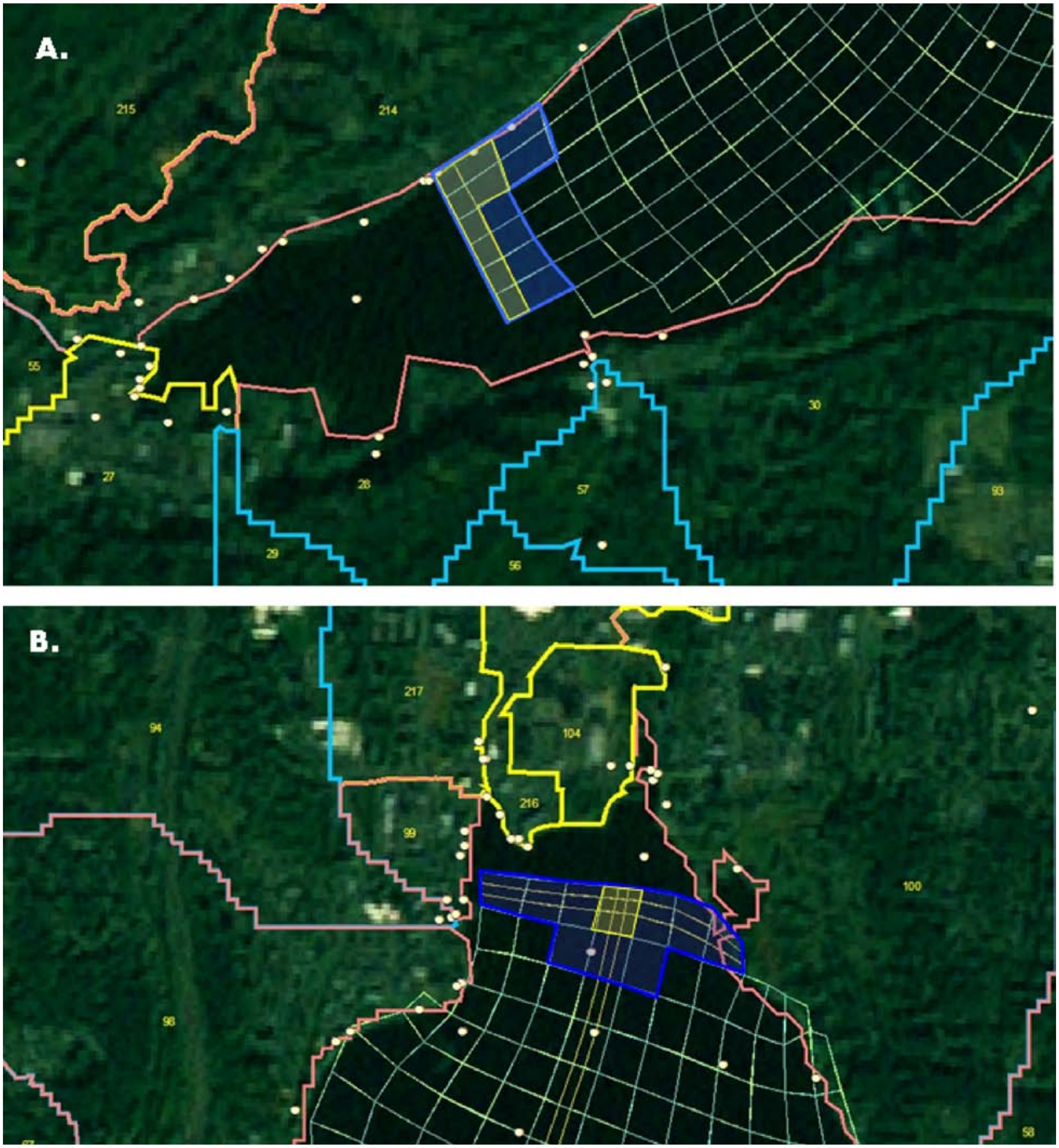


Figure 4-8. Diagram of the Gorst (A. 43-Sin-Gorst) and Clear (B. 03-Dyes-Clear) Creek canary nodes for the 94 x 105 (blue and yellow grids) and 91 x 96 (blue grid) model grids. The 91 x 96 canary nodes are highlighted in blue and the 95 x 105 canary nodes are highlighted in yellow. White dots show sampling station locations.

Where n was the number of observations, m was the number of simulation time steps (hourly) saved from the model run ($m = 24 \times 365 = 8760$), and SIM_i was the maximum simulated concentration in each group of nine canary nodes for the i^{th} time step. The frequency of exceeding standards was calculated for the output from the 91 x 96 and 94 x 105 grids. The frequencies were only calculated for canary nodes with 10 or more observations during WY2003.

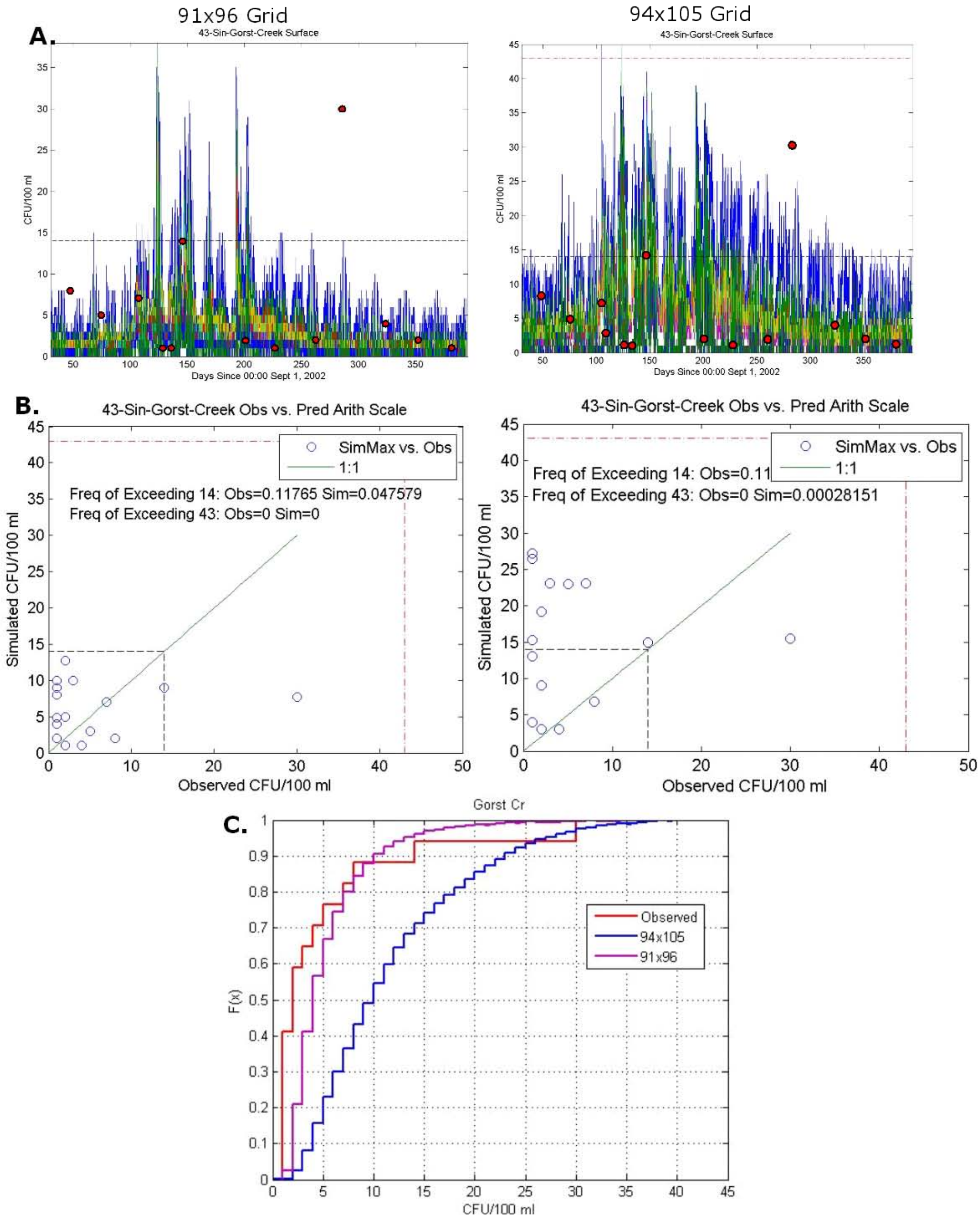


Figure 4-9. Comparison between observed and predicted FC concentrations for the Gorst Creek canary node showing time series (A), scatter plots (B), and CFD (C) generated from both grids.

The frequency that observed and simulated data exceeded WQ standards during WY2003 agreed well for most of the canary nodes, although there were some notable exceptions (Table 4-2). For Part I of the standard, the frequency of observed data exceeding 14 cfu/100 ml was much higher than the simulated frequency of exceedance for the canary nodes at 03-Dyes-Clear, 04-Dyes-Straw, 19-POP-

Dee, 33-PWN-AnCove, 35-RPass-Fort Ward, 48-Sin-Sacco, 59-Sin-Karcher, 52-Sin-SN10, and 53-Sin-SN11-12 (Figure 4-10A). Simulations from the refined 94 x 105 grid increased the frequency of exceeding 14 cfu/100 ml for 03-Dyes-Clear to 38%, which agreed with observed data, and 43-Sin-Gorst to 30%, which overpredicted observed data.

The higher resolution grid only slightly increased the frequency of exceeding 14 cfu/100 ml for the canary nodes at 04-Dyes-Straw, 49-Sin-SN03, and 51-Sin-Karcher (Figure 4-10A). The frequency of exceeding 43 cfu/100 ml by 10% or higher for the observed data occurred at 03-Dyes-Clear, 33-PWN-AnCove, 35-RPass-FortWard, and 51-Sin-Karcher canary nodes. For the simulated data from the 96 x 105 grid, only the canary nodes from 03-Dyes-Clear had a frequency > 1% of exceeding 43 cfu/100 ml (Figure 4-10B, Table 4-2).

Table 4-2. Summary of the frequency that observed and simulated data exceeded WQ standards of 14 and 43 cfu/100 ml during WY2003. The frequency was calculated using the maximum simulated values in each canary node for which there were 10 or more field observations during WY2003.

					91x96 (Max)		94x105 (Max)	
Canary Node		Observed			Simulated		Simulated	
Name	Number	n	Freq≥14	Freq≥43	Freq≥14	Freq≥43	Freq≥14	Freq≥43
01-Dyes-Barker-Cr-	01	26	3.8%	0.0%	0.3%	0.0%	0.2%	0.0%
02-Dyes-Chico-Cr--	02	30	26.7%	6.7%	0.0%	0.0%	0.0%	0.0%
03-Dyes-Clear-Cr--	03	18	38.9%	11.1%	5.2%	0.1%	37.6%	4.8%
04-Dyes-DY24-Straw	04	18	22.2%	5.6%	2.5%	0.0%	4.0%	0.1%
05-Dyes-DY28-Claml	05	16	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
07-Dyes-ErlandsPt-	07	13	7.7%	0.0%	0.0%	0.0%	0.0%	0.0%
10-Dyes-Windy-Pt--	10	11	9.1%	0.0%	0.0%	0.0%	0.0%	0.0%
11-Dyes-wShore----	11	11	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
12-Ostrich-Bay-M6-	12	15	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
13-Ostrich-eShore-	13	15	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
15-Ostrich-OBCreek	15	24	8.3%	0.0%	0.0%	0.0%	0.0%	0.0%
16-OysterBay-all--	16	16	6.3%	6.3%	0.0%	0.0%	0.0%	0.0%
17-PhinnyBay-sEnd-	17	16	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%
18-POP-SN17-Waterm	18	11	9.1%	0.0%	0.0%	0.0%	0.0%	0.0%
19-POP-Dee-Cr-----	19	11	36.4%	9.1%	0.0%	0.0%	0.0%	0.0%
22-POP-PO11-------	22	26	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
23-POPASS-PO12----	23	15	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
31-PWN-DY01-mouth-	31	11	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
33-PWN-AnCov-PineR	33	21	23.8%	14.3%	0.0%	0.0%	0.0%	0.0%
35-RPass-FortWard-	35	13	46.2%	23.1%	0.0%	0.0%	0.0%	0.0%
37-RPass-M2-midChn	37	16	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
38-RPas-SN18-Entra	38	11	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
43-Sin-Gorst-Creek	43	17	11.8%	0.0%	4.8%	0.0%	30.1%	0.0%
44-Sinclair-M3-mid	44	16	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
47-Sin-RossPt-SN08	47	11	9.1%	0.0%	0.0%	0.0%	0.0%	0.0%
48-Sinclair-SaccoC	48	11	18.2%	9.1%	0.0%	0.0%	0.0%	0.0%
49-Sin-SN03-PTOW--	49	16	6.3%	0.0%	0.4%	0.0%	1.0%	0.0%
51-SinPO-KarcherCr	51	16	31.3%	12.5%	0.2%	0.0%	1.9%	0.4%
52-SinPO-SN10-wfro	52	16	25.0%	0.0%	0.1%	0.0%	0.0%	0.0%
53-Sin-SN11-12mari	53	27	14.8%	3.7%	0.0%	0.0%	0.0%	0.0%

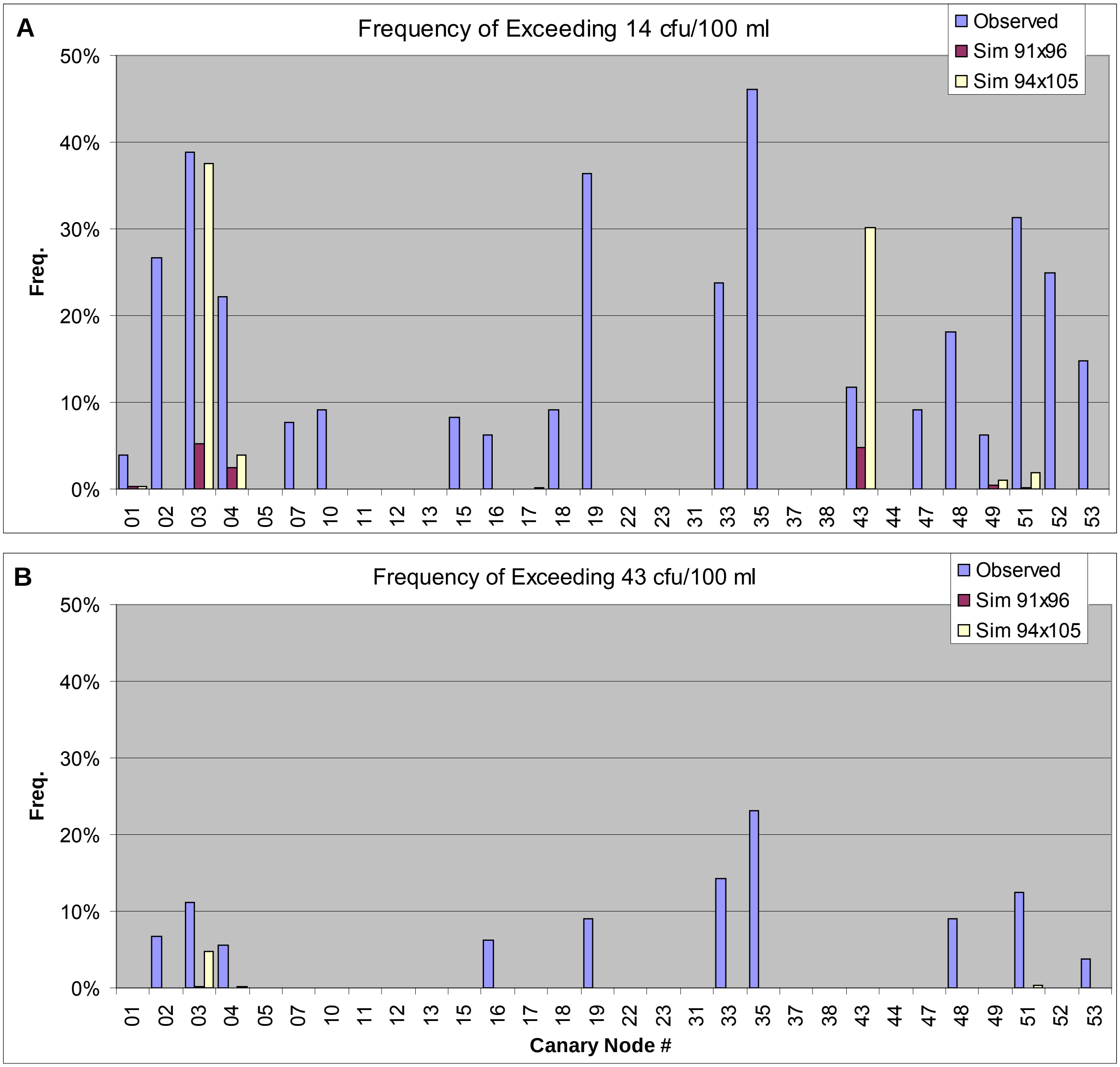


Figure 4-10. The frequency that observed and simulated data exceeded WQ standards of 14 (A) and 43 (B) cfu/100 ml during WY2003 for canary nodes with 10 or more observations. Results are shown for simulations using both grids.

A quantitative measure of how well the model fit the observed data was obtained by calculating the root-mean-square error (RMSE) between the observed (OBS_i) and predicted ($PRED_i$) values averaged over the number of observations (n):

$$\mathrm{RMSE}_{\mathrm{CN}} = \sqrt{\frac{\sum_{i=1}^{n}\left(OBS_i - PRED_i\right)^2}{n}} \qquad [16]$$

The RMSE was calculated for each canary node using the minimum ($RMSE_{min}$), average ($RMSE_{avg}$), and maximum ($RMSE_{max}$) values from the canary nodes for both grids. The RMSE was evaluated using the geometric progression of *e*, e^2, e^3, and e^4 as "cut-off" values corresponding to EXCELLENT, GOOD, FAIR, POOR, and VERY POOR (Table 4-3). The score was based on the average error ($RMSE_{avg}$) for each canary node with four or more observations. The geometric progression of *e* simply provides a convenient cut-off to score the magnitude of the error and provide a relative score for how well the model performed.

In addition to the RMSE, the evaluation also considered whether the overall observed geometric mean was the same, underpredicted, or overpredicted by the geometric mean of the simulation. The means were considered the same if the predicted geomean was within 2.72 cfu/100 ml (*e*) of the observed mean. It underpredicted or overpredicted if the predicted mean was greater than or less than 2.72 cfu/100 ml (*e*) the observed geomean.

Table 4-3. The cut-off values used to score the RMSE between observed and predicted data.

Score		RMSE
EXCELLENT	e	RMSE ≤ 2.72
GOOD	e^2	2.72 < RMSE ≤ 7.39
FAIR	e^3	7.39 < RMSE ≤ 20.09
POOR	e^4	20.09 < RMSE ≤ 54.60
VERY POOR	e^4	RMSE > 54.60

We used the RMSE calculated between the observed and predicted FC concentrations to rate how well the model performed in matching observed concentrations within the canary nodes (Table 4-4). The RMSE obtained for the minimum, average, and maximum canary node values were very similar, although the RMSE based on the maximum value generally resulted in the lowest error value. Both grids produced similar results, although there was a marked improvement in the predictions for canary node 03-Dyes-Clear with the 96 x 105 grid.

Table 4-4. Summary of the root mean square error (RMSE) between the observed and predicted FC concentration (cfu/100 ml), the simulated maximum geomean, and rating score obtained from simulations with the 91 x 96 (A) and 94 x 105 (B) grids for the canary nodes with four or more observations.

A. Predicted results from 91 x 96 grid.

	Observed			Predicted:91x96					
		arithmetic			RMSE		Geomean		Geomean
Group	n	average	geomean	RMSEmin	RMSEavg	RMSEmax	max	**Score**	Predicts
01-Dyes-Barker	26	3.35	2.18	5.96	5.58	4.90	1.32	**GOOD**	SAME
02-Dyes-Chico	30	12.27	5.48	17.03	16.92	16.83	0.25	**FAIR**	UNDER
03-Dyes-Clear	18	21.83	7.56	172.15	170.53	168.78	3.36	**VERY POOR**	UNDER
04-Dyes-Straw	18	14.86	4.19	41.21	41.06	40.48	1.39	**POOR**	UNDER
05-Dyes-ClamIS	16	1.86	1.62	2.48	2.45	2.44	0.06	**EXCELLENT**	SAME
07-Dyes-ErlandsPt	13	3.62	2.36	6.69	6.69	6.67	0.10	**GOOD**	SAME
08-Dyes-RockyPt	5	3.40	3.07	3.77	3.75	3.63	0.01	**GOOD**	UNDER
09-Dyes-MidWind	5	2.20	1.79	2.93	2.75	2.53	0.01	**GOOD**	SAME
10-Dyes-WindyP	11	3.94	2.67	6.98	6.98	6.98	0.19	**GOOD**	SAME
11-Dyes-wShore	11	2.59	2.30	3.33	3.33	3.33	0.01	**GOOD**	SAME
12-Ostrich-Bay	15	2.26	2.02	2.50	2.50	2.50	0.01	**EXCELLENT**	SAME
13-Ostrich-eShr	15	2.35	2.15	2.82	2.82	2.82	0.01	**GOOD**	SAME
14-Ostrich-JakPar	5	2.20	2.03	2.41	2.41	2.41	0.01	**EXCELLENT**	SAME
15-Ostrich-OBC	24	4.15	2.74	6.37	6.37	6.37	0.02	**GOOD**	UNDER
16-OysterBay	16	6.76	3.50	27.23	27.23	27.23	0.02	**POOR**	UNDER
17-PhinnyBay	16	4.50	3.32	4.84	4.82	4.82	0.07	**GOOD**	UNDER
18-POP-SN17	11	3.82	2.36	6.32	6.32	6.32	0.00	**GOOD**	SAME
19-POP-Dee-Cr	11	18.36	5.67	40.61	40.61	40.61	0.00	**POOR**	UNDER
20-POP-IllaheeSP	4	1.85	1.85	1.86	1.86	1.86	0.00	**EXCELLENT**	SAME
21-POP-M1	5	1.60	1.40	4.37	4.37	4.37	0.00	**GOOD**	SAME
22-POP-PO11	26	1.98	1.63	3.06	3.06	3.06	0.00	**GOOD**	SAME
23-POP-PO12	15	1.81	1.68	2.09	2.09	2.09	0.00	**EXCELLENT**	SAME
24-POP-SBCr	8	3.66	2.82	5.00	5.00	5.00	0.00	**GOOD**	UNDER
31-PWN-DY01	11	2.09	1.68	2.94	2.94	2.94	0.02	**GOOD**	SAME
32-PWN-Evrgrn	6	10.50	9.77	11.31	10.93	8.02	0.32	**FAIR**	UNDER
33-PWN-AnCov	21	106.14	7.16	436.90	436.90	436.90	0.05	**VERY POOR**	UNDER
34-RP-ClamBay	7	9.86	8.60	11.38	11.38	11.38	0.00	**FAIR**	UNDER
35-RP-FtWard-	13	137.30	21.62	374.92	374.92	374.92	0.00	**VERY POOR**	UNDER
36-RP-LynnC	5	96.40	72.57	107.71	107.65	107.45	0.16	**VERY POOR**	UNDER
37-RP-M2	16	1.38	1.27	1.62	1.62	1.62	0.00	**EXCELLENT**	SAME
38-RPas-SN18	11	2.18	1.48	4.07	4.07	4.07	0.00	**GOOD**	SAME
43-Sin-Gorst	17	4.94	2.95	8.30	7.69	7.78	3.80	**FAIR**	SAME
44-Sin M3	16	3.00	2.30	4.33	4.33	4.33	0.01	**GOOD**	SAME
45-Sin M4	5	7.93	6.53	9.25	9.25	9.25	0.02	**FAIR**	UNDER
47-Sin-SN08	11	3.64	2.54	5.74	5.74	5.74	0.05	**GOOD**	SAME
48-SaccoC	11	7.64	2.74	16.52	16.52	16.49	0.03	**FAIR**	SAME
49-Sin-SN03	16	3.81	2.43	6.92	5.94	5.00	0.60	**GOOD**	SAME
50-Sin-BlackJr	5	37.17	31.18	43.45	42.23	38.64	2.70	**POOR**	UNDER
51-Sin-Karcher	16	21.31	7.51	39.83	39.52	38.48	1.54	**POOR**	UNDER
52-SinSN10	16	8.63	4.92	13.48	13.15	12.06	0.47	**FAIR**	UNDER
53-Sin-SN11	27	9.96	4.41	20.49	20.44	20.33	0.09	**POOR**	UNDER

Table 4-4 (continued).

B. Predicted results from 94 x 105 grid.

	Observed			Predicted: 94x105					
		arithmetic		RMSE			Geomean		Geomean
Group	n	average	geomean	RMSEmin	RMSEavg	RMSEmax	max	Score	Predicts
01-Dyes-Barker	26	3.35	2.18	5.9625	5.5930	4.5742	1.30	GOOD	SAME
02-Dyes-Chico	30	12.27	5.48	27.0802	26.8926	26.5364	0.52	POOR	UNDER
03-Dyes-Clear	18	21.83	7.56	48.1843	45.6025	41.7123	8.73	POOR	SAME
04-Dyes-Straw	18	14.86	4.19	41.2053	40.6246	38.0623	1.71	POOR	SAME
05-Dyes-ClamIS	16	1.86	1.62	2.4517	2.3806	2.2289	0.08	EXCELLENT	SAME
07-Dyes-ErlandsPt	13	3.62	2.36	6.6884	6.6732	6.6679	0.18	GOOD	SAME
08-Dyes-RockyPt	5	3.40	3.07	3.7683	3.7221	3.5777	0.02	GOOD	UNDER
09-Dyes-MidWind	5	2.20	1.79	2.9326	2.9254	2.8983	0.02	GOOD	SAME
10-Dyes-WindyP	11	3.94	2.67	6.9793	6.9793	6.9793	0.20	GOOD	SAME
11-Dyes-wShore	11	2.59	2.30	3.1685	3.1685	3.1685	0.02	GOOD	SAME
12-Ostrich-Bay	15	2.26	2.02	2.7810	2.7810	2.7810	0.02	GOOD	SAME
13-Ostrich-eShr	15	2.35	2.15	2.8231	2.8231	2.8231	0.01	GOOD	SAME
14-Ostrich-JakPar	5	2.20	2.03	2.4083	2.4083	2.4083	0.01	EXCELLENT	SAME
15-Ostrich-OBC	24	4.15	2.74	6.7889	6.5317	5.6721	0.39	GOOD	SAME
16-OysterBay	16	6.76	3.50	13.3164	13.2925	13.1965	0.11	FAIR	UNDER
17-PhinnyBay	16	4.50	3.32	5.8843	5.8448	5.8149	0.11	GOOD	UNDER
18-POP-SN17	11	3.82	2.36	6.3246	6.3246	6.3246	0.00	GOOD	SAME
19-POP-Dee-Cr	11	18.36	5.67	40.6090	40.6090	40.6090	0.00	POOR	UNDER
20-POP-IllaheeSP	4	1.85	1.85	1.8561	1.8561	1.8561	0.00	EXCELLENT	SAME
21-POP-M1	5	1.60	1.40	2.0000	2.0000	2.0000	0.00	EXCELLENT	SAME
22-POP-PO11	26	1.98	1.63	3.0566	3.0566	3.0566	0.00	GOOD	SAME
23-POP-PO12	15	1.81	1.68	2.0497	2.0497	2.0497	0.00	EXCELLENT	SAME
24-POP-SBCr	8	3.66	2.82	5.0036	5.0036	5.0036	0.00	GOOD	UNDER
31-PWN-DY01	11	2.09	1.68	2.9388	2.9328	2.8956	0.03	GOOD	SAME
32-PWN-Evrgrn	6	10.50	9.77	11.3063	10.9336	8.0208	0.32	FAIR	UNDER
33-PWN-AnCov	21	106.14	7.16	436.9002	436.8820	436.7401	0.05	VERY POOR	UNDER
34-RP-ClamBay	7	9.86	8.60	11.3829	11.3829	11.3829	0.00	FAIR	UNDER
35-RP-FtWard-	13	137.30	21.62	374.9151	374.9151	374.9151	0.00	VERY POOR	UNDER
36-RP-LynnC	5	96.40	72.57	107.7089	107.7089	107.7089	0.04	VERY POOR	UNDER
37-RP-M2	16	1.38	1.27	1.6202	1.6202	1.6202	0.00	EXCELLENT	SAME
38-RPas-SN18	11	2.18	1.48	4.0676	4.0676	4.0676	0.00	GOOD	SAME
43-Sin-Gorst	17	4.94	2.95	8.4344	7.9217	15.5851	7.92	FAIR	OVER
44-Sin M3	16	3.00	2.30	4.3301	4.3301	4.3301	0.00	GOOD	SAME
45-Sin M4	5	7.93	6.53	9.8049	9.8049	9.8049	0.02	FAIR	UNDER
47-Sin-SN08	11	3.64	2.54	5.7366	5.7366	5.7366	0.00	GOOD	SAME
48-SaccoC	11	7.64	2.74	16.5200	16.4838	16.4012	0.03	FAIR	SAME
49-Sin-SN03	16	3.81	2.43	6.9192	6.3462	5.1499	0.87	GOOD	SAME
50-Sin-BlackJr	5	37.17	31.18	43.4454	42.3000	40.1448	1.86	POOR	UNDER
51-Sin-Karcher	16	21.31	7.51	39.8285	39.6079	40.0407	0.36	POOR	UNDER
52-SinSN10	16	8.63	4.92	13.4815	13.4188	13.2971	0.05	FAIR	UNDER
53-Sin-SN11	27	9.96	4.41	20.4912	20.4837	20.4749	0.06	POOR	UNDER

Most of the canary nodes (75%) achieved a FAIR to EXCELLENT rating for the 91 x 96 and 94 x 95 girds, particularly canary nodes located in the middle of inlets away from the direct influence of sources along the shore. Similarly, the predicted geomean was within 10 cfu/100 ml of the observed geomean except for the canary nodes located at 35-RPass-FortWard, 36-RPass-LynnC, and 50-Sin-BlackJ (Figure 4-11). The observed geomean tended to be higher than the simulated values, probably because the observed geomean was influenced by nondetected values that were reported as 1 cfu/ 100 ml and treated as such in the statistical calculations. The simulated geomean represents the average over all the simulated output (hourly time steps for 1 year), while the RMSE is based on

individual observations that are influenced by the conditions present during the sampling events such as rain, wind, or tides that may result in slight lag or variations in the timing of the sample and the simulated result. The canary node grouping accounted for spatial averaging of the predicted data, but no attempt was made to average the predicted values over time. The RMSE was calculated using the simulated value within 1 hour of the observation, but in many cases the simulated value was rapidly changing over time and slight offsets in timing could result in large errors between the observed and predicted values. Plots for 03-Dyes-Clear on day 65 and day 108 can be viewed as examples on the distribution CD or via the internet (Table 1-1). Another factor is that the simulated results are based on the modeled inputs that were set to the geomean (50th percentile) for the FC loading concentration so the results evaluated do not represent the full range of FC loading expected from the watershed (see Section 3.2).

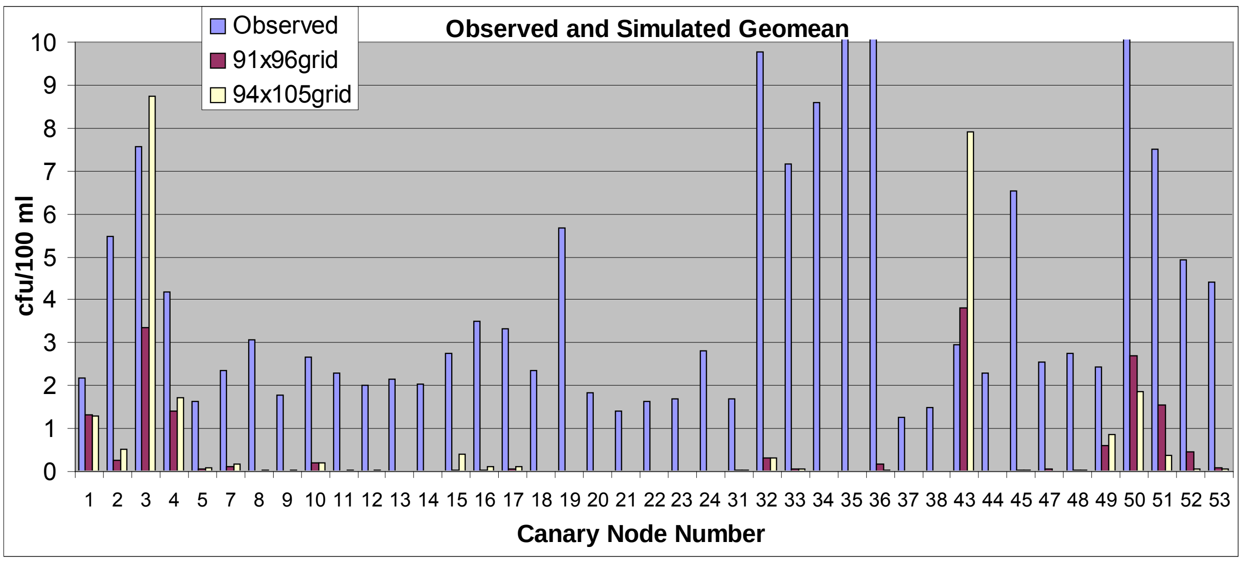


Figure 4-11. Comparison between observed and simulated geomeans (n ≥ 4).

The simulation results from both grids were very similar except that the 94 x 105 grid improved the predictions for 03-Dyes-Clear, 16-OysterBay, and 21-POP-M1 and worsened the predictions for 02-Dyes-Chico, 12-OstrichBay, and 43-Sin-Gorst (Table 4-5). The simulated results for 43-Sin-Gorst were the only canary nodes that overpredicted the observed FC levels (Figure 4-11).

Diagrams of the model evaluation results for FC loading from the watershed DSNs (rectangles) and canary nodes (circles) for predicting FC concentrations in Sinclair and Dyes Inlets during WY2003 are shown in Figure 4-12. For Dyes Inlet, GOOD to EXCELLENT ratings were obtained for all the canary nodes located in the middle of the inlet, while VERY POOR and POOR ratings were only obtained for some the nearshore canary nodes for 03-Dyes-Clear, 04-Dyes-Straw, and 02-Dyes-Chico (Figure 4-12). Underpredicting the loads from Strawberry and Clear Creeks probably contributed to the low ratings for the canary nodes at the head of Dyes Inlet, suggesting that the model did not account for all the sources of FC in that area. Chico Bay was rated FAIR, even though there was GOOD agreement with the loads from Chico Creek. The underprediction of FC concentrations within the intertidal areas of Chico Creek was probably due to intermittent sources such as failing on-site sewage systems, wildlife, waterfowl, or leaking sewer infrastructure (KCHD 2005).

Table 4-5. Comparison between the rating scores obtained using the average RMSE calculated from the 91 x 96 and 94 x 105 grids.

	Predicted: 91x96			Predicted: 94x105			Comparison of Grids
Group	Average RMSE	Rating	Geomean Predicts	Average RMSE	Rating	Geomean Predicts	
01-Dyes-Barker-Cr-	5.6	GOOD	SAME	5.59	GOOD	SAME	no change
02-Dyes-Chico-Cr--	16.9	FAIR	UNDER	26.89	POOR	UNDER	**worsened**
03-Dyes-Clear-Cr--	170.5	VERY POOR	UNDER	45.60	POOR	SAME	**very improved**
04-Dyes-DY24-Straw	41.1	POOR	UNDER	40.62	POOR	SAME	improved slightly
05-Dyes-DY28-ClamI	2.5	EXCELLENT	SAME	2.38	EXCELLENT	SAME	no change
07-Dyes-ErlandsPt-	6.7	GOOD	SAME	6.67	GOOD	SAME	no change
08-Dyes-M5-RockyPt	3.8	GOOD	UNDER	3.72	GOOD	UNDER	no change
09-Dyes-M7-MidWind	2.8	GOOD	SAME	2.93	GOOD	SAME	no change
10-Dyes-Windy-Pt--	7.0	GOOD	SAME	6.98	GOOD	SAME	no change
11-Dyes-wShore----	3.3	GOOD	SAME	3.17	GOOD	SAME	improved slightly
12-Ostrich-Bay-M6-	2.5	EXCELLENT	SAME	2.78	GOOD	SAME	**worsened**
13-Ostrich-eShore-	2.8	GOOD	SAME	2.82	GOOD	SAME	no change
14-Ostrich-JackPar	2.4	EXCELLENT	SAME	2.41	EXCELLENT	SAME	no change
15-Ostrich-OBCreek	6.4	GOOD	UNDER	6.53	GOOD	SAME	no change
16-OysterBay-all--	27.2	POOR	UNDER	13.29	FAIR	UNDER	**improved**
17-PhinnyBay-sEnd-	4.8	GOOD	UNDER	5.84	GOOD	UNDER	worsend slightly
18-POP-SN17-Waterm	6.3	GOOD	SAME	6.32	GOOD	SAME	no change
19-POP-Dee-Cr-----	40.6	POOR	UNDER	40.61	POOR	UNDER	no change
20-POP-IllaheeSPCr	1.9	EXCELLENT	SAME	1.86	EXCELLENT	SAME	no change
21-POP-M1-MidChann	4.4	GOOD	SAME	2.00	EXCELLENT	SAME	**improved**
22-POP-PO11-------	3.1	GOOD	SAME	3.06	GOOD	SAME	no change
23-POPASS-PO12----	2.1	EXCELLENT	SAME	2.05	EXCELLENT	SAME	no change
24-POP-SpringBroCr	5.0	GOOD	UNDER	5.00	GOOD	UNDER	no change
31-PWN-DY01-mouth-	2.9	GOOD	SAME	2.93	GOOD	SAME	no change
32-PWN-EvergrnPark	10.9	FAIR	UNDER	10.93	FAIR	UNDER	no change
33-PWN-AnCov-PineR	436.9	VERY POOR	UNDER	436.88	VERY POOR	UNDER	no change
34-RPass-ClamBay--	11.4	FAIR	UNDER	11.38	FAIR	UNDER	no change
35-RPass-FortWard-	374.9	VERY POOR	UNDER	374.92	VERY POOR	UNDER	no change
36-RPass-LynhwoodC	107.7	VERY POOR	UNDER	107.71	VERY POOR	UNDER	no change
37-RPass-M2-midChn	1.6	EXCELLENT	SAME	1.62	EXCELLENT	SAME	no change
38-RPas-SN18-Entra	4.1	GOOD	SAME	4.07	GOOD	SAME	no change
43-Sin-Gorst-Creek	7.7	FAIR	SAME	7.92	FAIR	OVER	no change
44-Sinclair-M3-mid	4.3	GOOD	SAME	4.33	GOOD	SAME	no change
45-Sinclair-M4-mid	9.3	FAIR	UNDER	9.80	FAIR	UNDER	worsened slightly
47-Sin-RossPt-SN08	5.7	GOOD	SAME	5.74	GOOD	SAME	no change
48-Sinclair-SaccoC	16.5	FAIR	SAME	16.48	FAIR	SAME	no change
49-Sin-SN03-PTOW--	5.9	GOOD	SAME	6.35	GOOD	SAME	no change
50-SinPO-BlackJ-Cr	42.2	POOR	UNDER	42.30	POOR	UNDER	no change
51-SinPO-KarcherCr	39.5	POOR	UNDER	39.61	POOR	UNDER	no change
52-SinPO-SN10-wfro	13.1	FAIR	UNDER	13.42	FAIR	UNDER	no change
53-Sin-SN11-12mari	20.4	POOR	UNDER	20.48	POOR	UNDER	no change

For the canary nodes in Sinclair Inlet, Port Washington Narrows, and around the City of Bremerton, the evaluation showed that the model underpredicted FC levels in Oyster Bay, Anderson Cove/Lions Park, near the mouths of Dee Creek and Olney (Karcher) Creek, and along the Port Orchard waterfront (Figure 4-13). However, there was FAIR to GOOD agreement between the model and observed data for Ostrich Bay, Phinney Bay, Evergreen Park, and within Sinclair Inlet. Evaluation of the canary nodes in central Sinclair Inlet or the nearshore areas around the Shipyard required more data than was available. The POOR and VERY POOR ratings for loading from the stormwater basins in Bremerton and Port Orchard and the high variability inherent in the FC data probably contributed to the mismatch between model predictions and observed data. The mismatch between model predictions and observed data may also be an indication that additional FC sources are present that are not included in the model. In this manner, the model maybe a diagnostic that additional FC sources are present in Oyster Bay, Dee Creek, and along the Port Orchard waterfront, including Blackjack Creek. Additional sources could include other stormwater outfalls, wildlife, and marinas located in those areas. The VERY POOR rating for the Anderson Cove/Lions Park canary node in the Port Washington Narrows may be due to the model's inability to resolve the small cove along the channel dominated by high current speeds in the Narrows.

Similar to the results obtained for Dyes Inlet, there was good agreement between the model predictions and observed data for the canary nodes located out in the inlet away from close proximity to the sources on the shoreline (Figure 4-14). The model performed well for the canary nodes at the mouth of the Port Washington Narrows, the main channel of Sinclair Inlet, near the mouth of Ross Creek, and near the West Bremerton WWTP outfall. The observed FC geomean concentration (3.0 cfu/100 ml) for the canary nodes in Gorst was overpredicted by the results from the 94 x 105 grid (8.0 cfu/100 ml), but there was good agreement for the predicted geomean obtained from the 91 x 96 grid (3.8 cfu/100 ml, Table 3-3).

The canary nodes in Port Orchard and Rich Passages (Figure 4-14) also showed good agreement with the observed data receiving GOOD to EXCELLENT scores for the entrance to Fletcher Bay, throughout Port Orchard Passage and at the mouth of Rich Passage. However, nearshore canary nodes in Clam Bay, along the southern coast of Bainbridge Island in Lynnwood Cove, and near Fort Ward did not agree well with observed data. Although there were very low numbers of observations for the Bainbridge Island stations, the underpredictions from the model could be indications that other sources of FC are present in these areas. Possible sources in the area include unknown drainages from the shoreline, waterfowl (possibly from the Schel-Chelb estuary), salmon-rearing pens, marine mammals, or other unknown sources. The low predictions for Clam Bay compared to the observed data are probably due to the model's inability to resolve Clam Bay very well since the grids in that area are dominated by the high current speeds in Rich Passage.

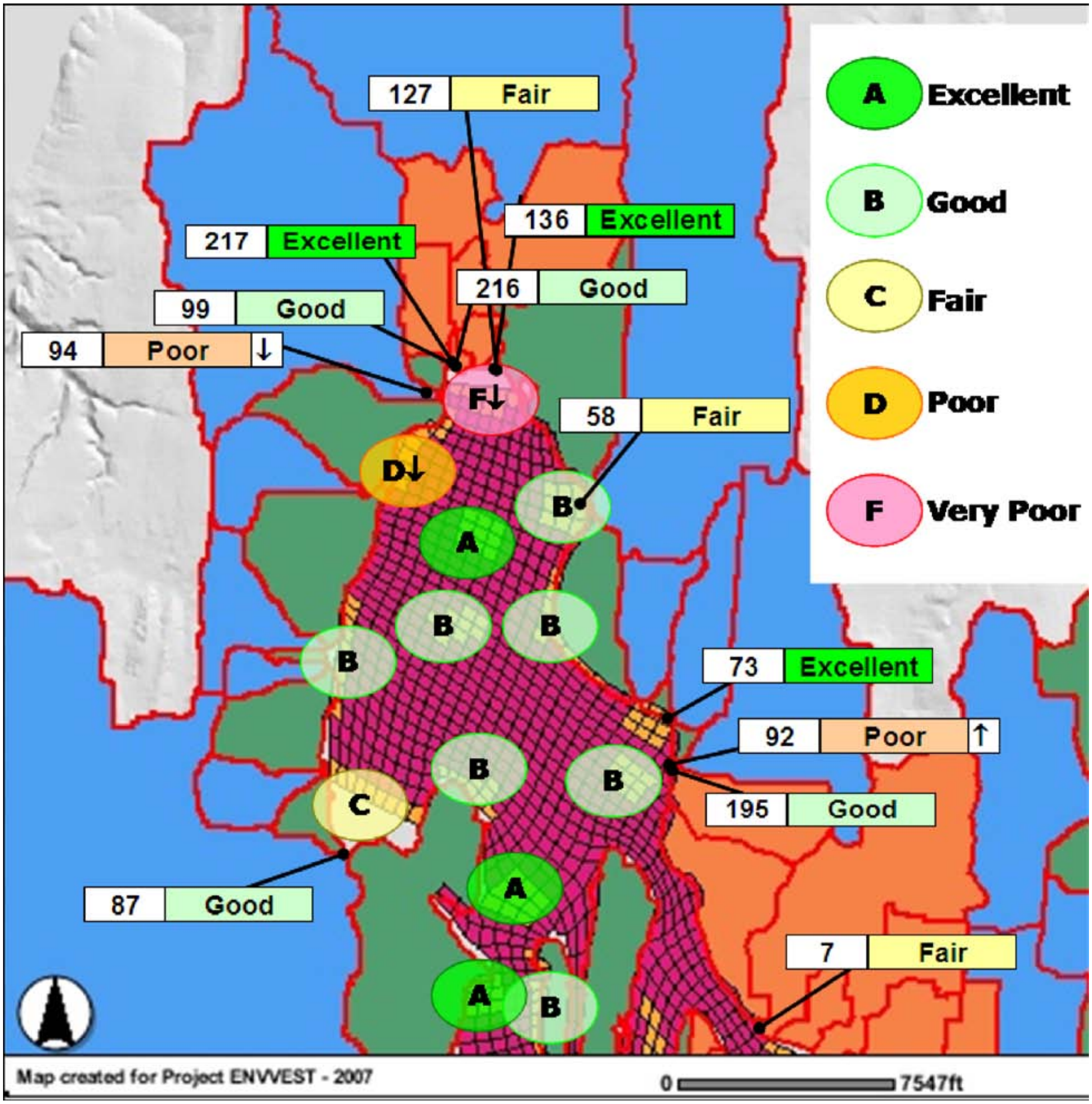


Figure 4-12. Model evaluation results for estimating FC loading from watershed DSNs (rectangles) and predicting FC concentrations at canary nodes (circles) in Dyes Inlet during WY2003. See Table 3-3 for a summary of comparison between observed and simulated FC loading (FC counts/hr) from watershed Data Set Numbers (DSNs) and see Table 4-4 for summary of the root mean square error (RMSE) between the observed and predicted FC concentration (cfu/100 ml) for each canary node.

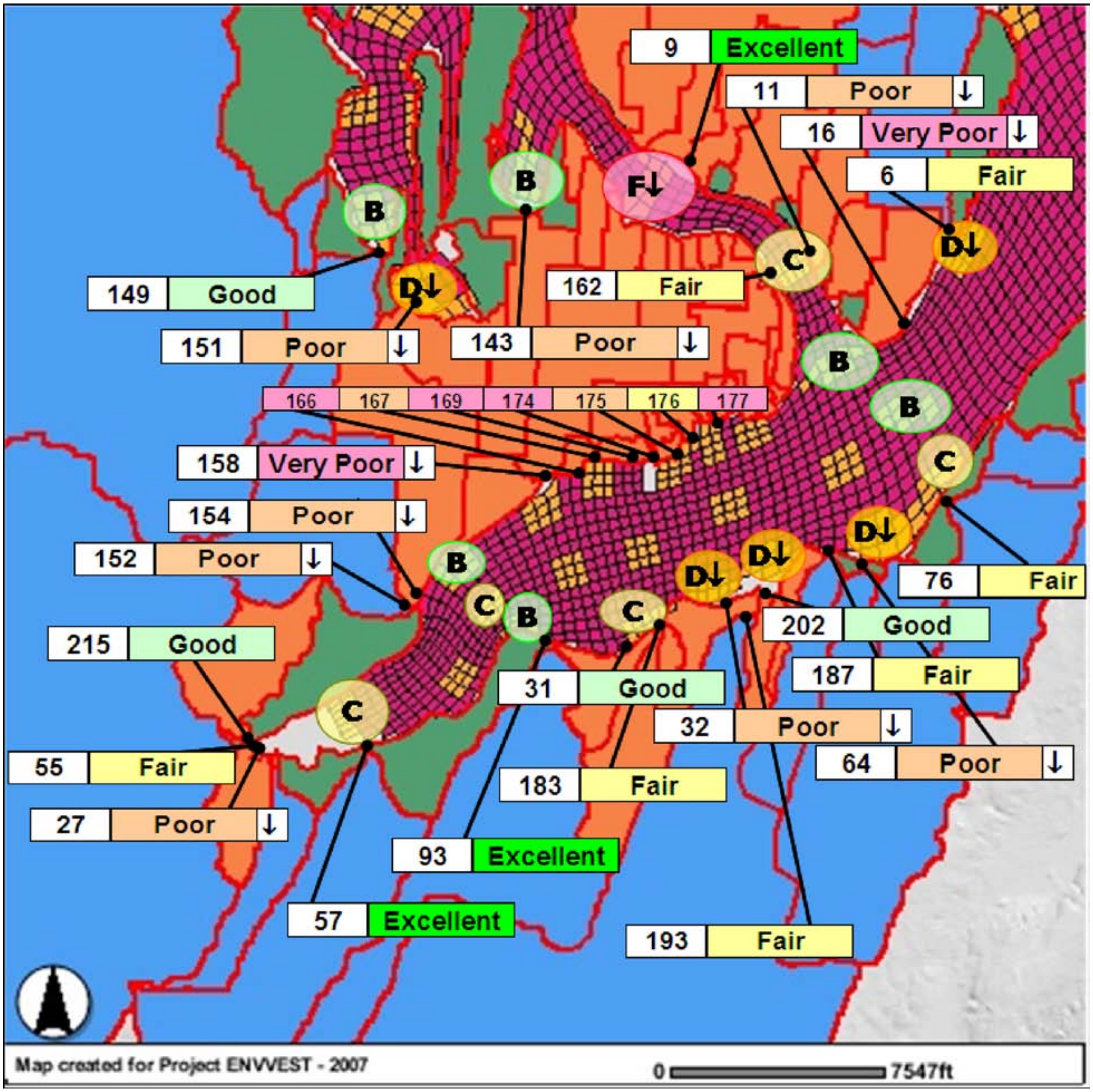


Figure 4-13. Model evaluation results for estimating FC loading from watershed DSNs (rectangles) and predicting FC concentrations at canary nodes (circles) in Sinclair Inlet, Port Washington Narrows, Phinney Bay, Ostrich Bay, and Oyster Bay (see Figure 4-12 for legend).

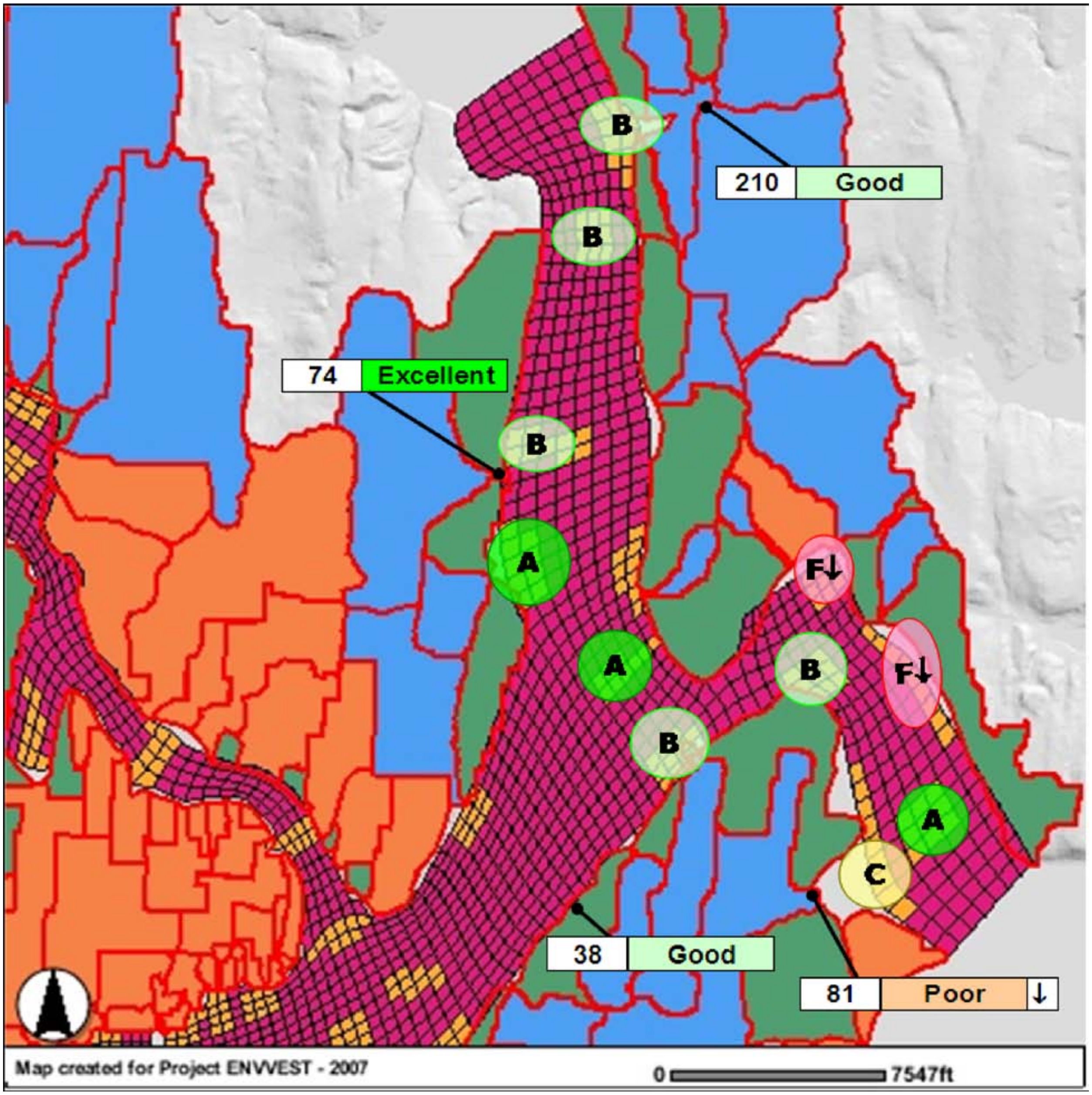


Figure 4-14. Model evaluation results for estimating FC loading from watershed DSNs (rectangles) and predicting FC concentrations at canary nodes (circles) in Port Orchard and Rich Passages. See Figure 4-12 for figure legend.

The evaluation helped to identify the uncertainty associated with the model's predictions; nevertheless, the model produced very plausible results that showed good agreement with the available data. There were only a handful of canary nodes with a geomean concentration that differed by more than 7 cfu/100 ml from the observed data (Figure 4-11). These were canary nodes located in the main channel of the Port Washington Narrows (32-PWN-Evrgrn and 33-PWN-AnCove), the main channel of Rich Passage (34-RP-ClamBay), along the south shore of Bainbridge Island (35-RP-FtWard and 36-RP-LynnCove), and the mouth of Blackjack Creek (50-Sin-BlackJ). There was less certainty for the model's predictions in the nearshore areas that were rated POOR and VERY POOR, including the mouths of Clear, Strawberry, Chico, Dee, Olney, and Blackjack Creeks

and along the Port Orchard waterfront. Most likely, the model did not capture all the sources of FC loading in those areas.

Overall, we concluded that the model performed very well. It recreated a wide range of dynamic loading within the inlets, from large-scale storm events with high-flow conditions to dry, low-flow conditions during the summer months. Although data were limited for many of the stations in Sinclair Inlet, especially near the Shipyard and other areas likely to receive stormwater runoff from the Cities of Bremerton and Port Orchard, the model reproduced FC loading episodes with a high degree of accuracy.

Based on the data available, we had a high degree of confidence that CH3D-FC could simulate FC concentrations in the inlets. There was GOOD to EXCELLENT agreement with observed data for marine waters; however, there was a tendency to underpredict FC concentrations in certain nearshore areas. The nearshore areas that were underpredicted by the model were identified as Clear/Strawberry, Oyster Bay, Dee, Port Orchard waterfront, and the southern shore of BI.

4.5 Sensitivity Analysis

We conducted sensitivity analysis to evaluate the sensitivity of model predictions to specific sets of input parameters, including FC loading concentration, stream and storm water flow, wind, and FC bacterial die-off. The May 2004 simulation was selected for the sensitivity analysis. The parameter being evaluated was changed to evaluate the difference from the base condition, while all other parameters were held constant. The base condition was the geomean FC loading for the May 2004 storm event (S5). The results were compared to the effect of varying FC concentrations to the 25th percentile (S4) and the 75th percentile (S6), increasing flow by 20% (S14), increasing flow by a factor of 2 (S15), applying a constant wind speed of 10 m/sec (22.6 mph) from the SW (S16), and eliminating bacterial decay to simulate FC inputs as a conservative tracer (S17). The input data and simulation results are available on the distribution CD or via the internet (Table 1-1).

The 26 to 27 May 2004 storm event was assumed to represent a "typical" storm event. The storm generated about 1.3 to 2.6 inches of rain within the study area with the peak intensity occurring on the morning of 27 May. The storm occurred following a relatively dry period of little to no rain, allowing the effects of the storm to be reasonably distinct from baseflow conditions.

4.5.1 FC Concentration Effect

We compared the geomean FC loading for the May 2004 storm event (S5 base condition) to the effect of varying FC concentrations (S4, 25th percentile and S6, 75th percentile) for the stream, stormwater, shoreline, and WWTP pour points in the model. An example of the effect of varying the FC loading concentration is shown for the mouth of Clear Creek in Figure 4-15. The FC loads at this location were dominated by the loads from the main stem of Clear Creek (DSN126), which was set to 11, 97, and 294 cfu/100 ml for the 25th, 50th (geomean), and 75th percentiles, respectively. The simulation results showed that the 25th percentile resulted in very low concentrations, the geomean elevated concentrations during the storm event, and the 75th percentile loading concentration roughly doubled the FC concentrations relative to the base simulation, but the concentrations did not exceed the water quality standard of 14 cfu/100 ml at any time during the during the storm event (Figure 4-15).

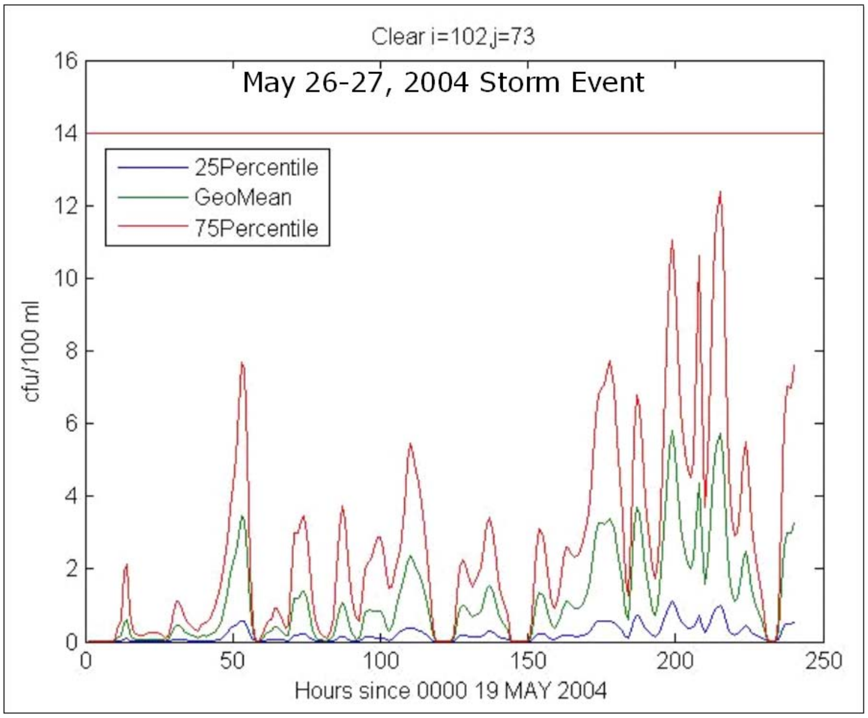


Figure 4-15. The effect of FC concentration predicted at the mouth of Clear Creek as a function of the FC loading concentration.

The FC plume associated with the varying concentrations is shown in Figure 4-16A–C. The maximum extent of the plume generated by the storm event occurred at about 1800 on May 28th. The 25th percentile FC loading concentration did not generate plumes with concentrations >14 cfu/100 ml (Figure 4-16A). Plumes generated by the 50th percentile exceeded 14 cfu/100 ml in Northern Dyes Inlet, near the Shipyard, near the Bremerton WWTP outfall (SN03), and near the mouth of Olney Creek (Figure 4-16B). The plumes generated by the 75th percentile extended even further out into the marine waters of the inlets, and additional plumes were evident near Barker, Gorst, and Blackjack Creeks (Figure 4-16C).

4.5.2 Flow Effect

We evaluated effect of flow by keeping the FC loading concentration constant (set to 50th percentile) and increasing the freshwater flow by 20% (S14) and 100% (S15). The effect of increasing flows from all streams and outfalls 1.2 and 2.0 (flows from the WWTPs were held constant) is shown in Figure 4-16D–F. Increasing the flow showed only slight increases in the plume compared to the base simulation. However, the concentrations in the plumes appeared to intensify slightly when the flows were doubled, probably due to the fact the loads were also doubled during the storm event (Figure 4-16F).

4.5.3 Wind Effect

We evaluated the effect of wind by adding a constant wind of 10 m/s (22 mph) from the SE (S16). The wind only caused slight variations in the shape of the plume from the base simulation (Figure 4-17B. The wind was applied over the whole model domain for the entire simulation period (10

days), so the simulation greatly overestimated the effect of wind, which usually occurs over relatively short periods (< 1 day). However, the effect of wind could be important in certain areas, such as the middle of Dyes Inlet and out in the passages where localized current patterns can develop as a function of wind (Wang et al., 2005).

4.5.4 FC Die-Off Effect

We evaluated the effect of FC die-off kinetics by eliminating bacterial die-off. This had a dramatic effect on the simulation results (Figure 4-17C). Without any die-off, the discharges of FC behaved like a conservative substance, the only reduction in concentration was due to physical mixing and dispersion. Under these conditions the plumes were much greater in Northern Dyes Inlet, along the northern shore of Sinclair Inlet near the Shipyard and SN03, and near the mouths of Gorst, Blackjack, and Olney Creeks. The fact that the plumes did not cover the inlets completely shows how important physical mixing is in dispersing the FC. The plumes were not maintained in areas with high current velocities and were quickly dispersed in the Port Washington Narrows, Port Orchard and Rich Passages, and the main basins of the Sinclair and Dyes Inlets.

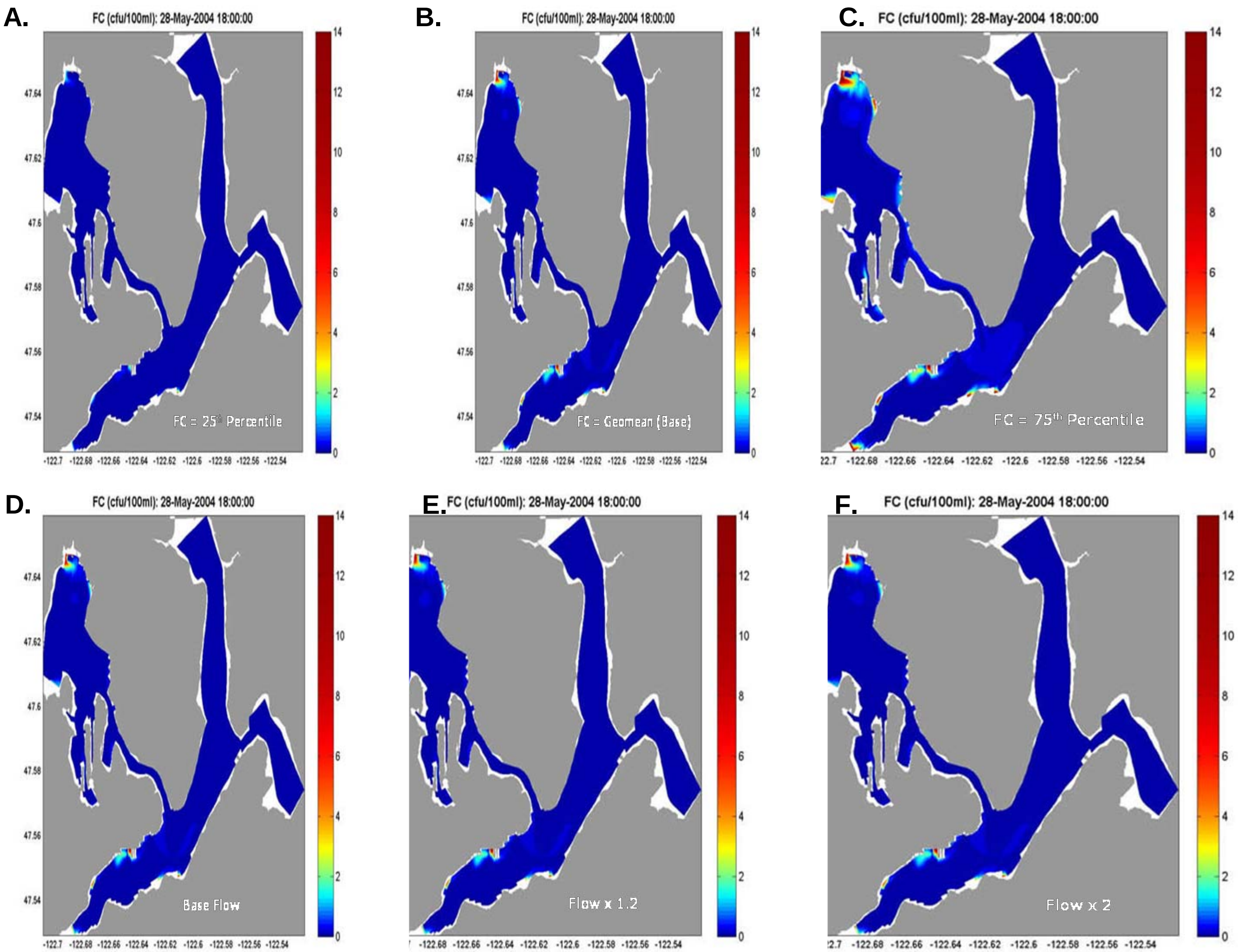


Figure 4-16. Results of sensitivity analysis for simulation of the May 2004 storm event showing the extent of the plume at 1800 on 28 May for varying FC loading concentrations set to the 25th (A), 50th (B., geomean base simulation), and 75th percentile (C), and varying flow conditions for the base flow (D), flows increased by 20% (E), and flows increased by 100% (F).

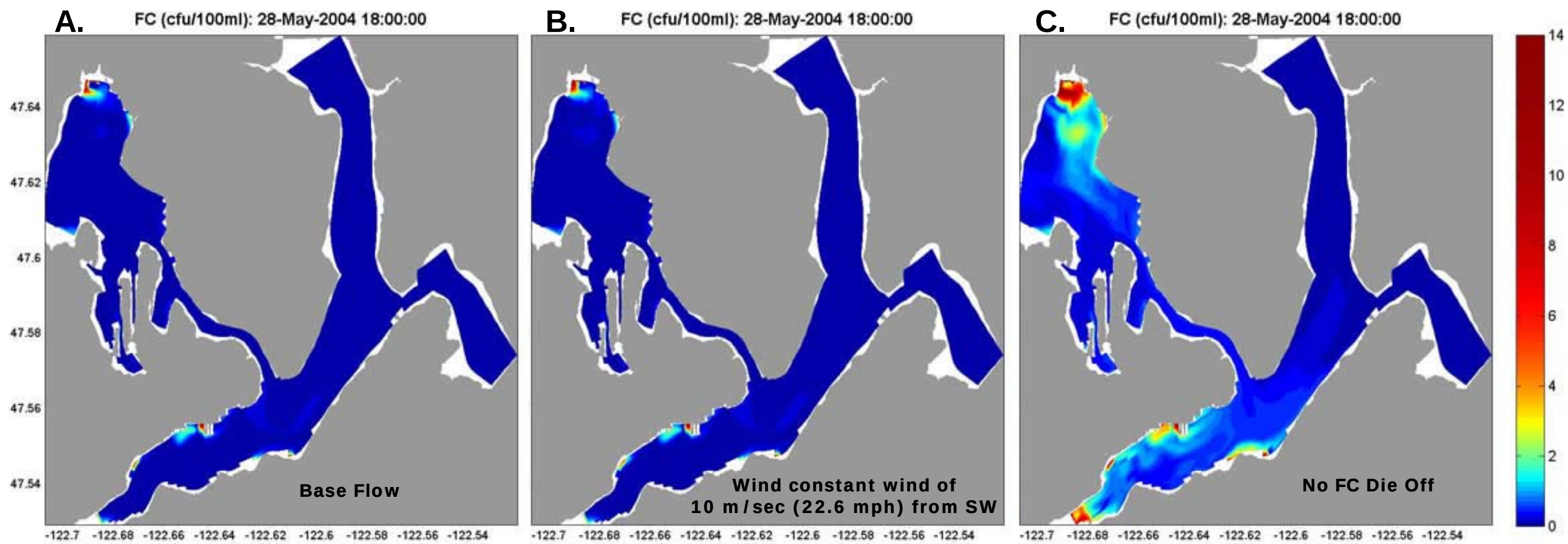


Figure 4-17. Results of sensitivity analysis for simulation of the May 2004 storm event showing the extent of the plume at 1800 on 28 May for no wind.

4.5.5 Summary of Sensitivity Analysis

The relative importance of each of the parameters evaluated in the sensitivity analysis is shown for a grid cell located in the middle of Northern Dyes Inlet (*i* = 91, *j* = 68, using the 94 x 105 grid) in Figure 4-18. The highest concentrations occurred when there was no bacterial die-off (S17), followed by the 75th percentile loading concentration (S6). The peaks for the no die-off and 75th percentile occurred very closely. The decay due to UV radiation during the daylight hours is apparent in the difference between the S17 and S6 time series. The effect of wind (S16) and increasing flow (S14 and S15) only had minor effects on the FC concentrations compared to the base simulation (S5).

The sensitivity analysis showed that the most important factors affecting the distribution of FC in the inlets were the FC loading, which was controlled by the loading concentration and freshwater flows, physical mixing, and FC die-off. Wind and small changes to freshwater flows did not appear to have much effect on the FC distribution in the inlets.

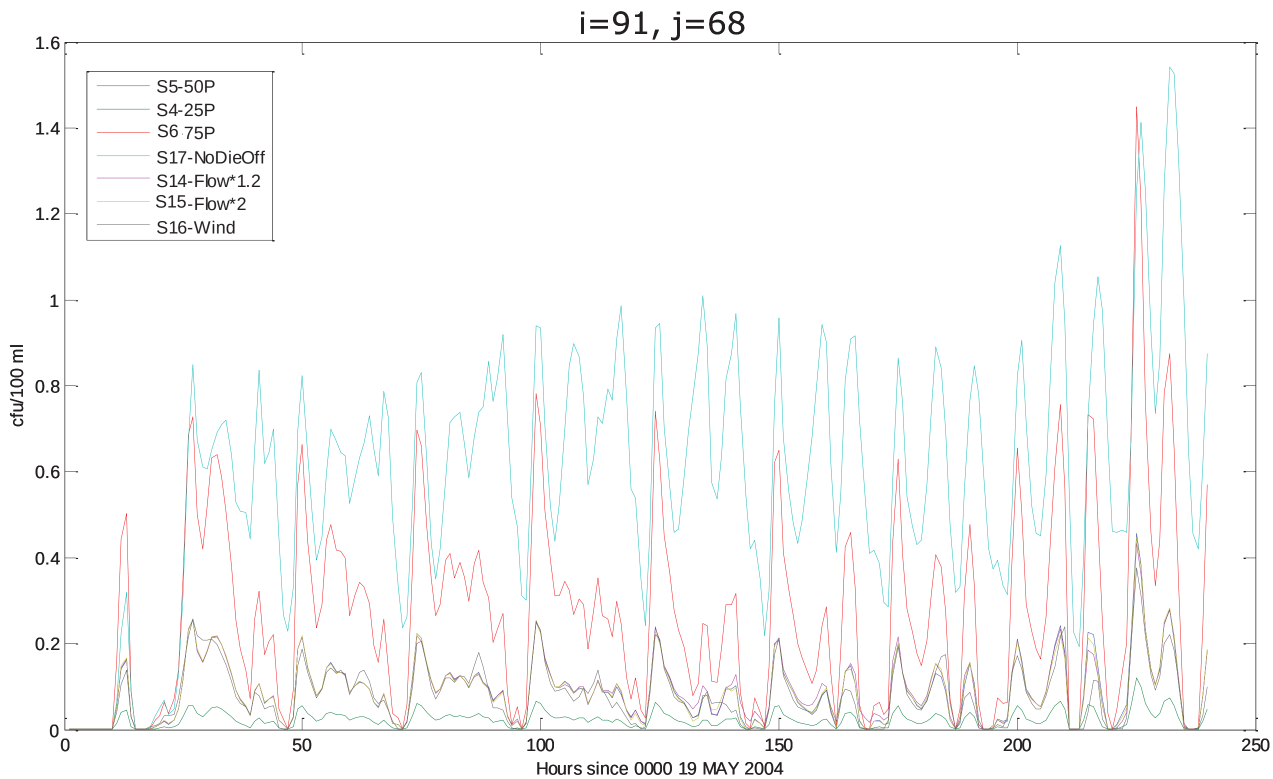


Figure 4-18. The FC levels simulated for a surface grid in the middle of Northern Dyes Inlet for the geomean FC loading concentration (S5 -Base), the 25th (S4) and 75th percentiles (S6) FC loading concentration, no FC die-off (S17), flow increased by 1.2 (S14) and 2.0 (S15), and wind (S16).

4.6 Uncertainty Analysis

The sensitivity analysis evaluated parameters that are known to vary to determine their impact on predicted FC concentrations. For the uncertainty analysis we evaluated factors that were thought to be extremely important, but the effect on FC loading was unknown or speculative at best. These factors are those that will be affected by future growth and development, resulting in changes to the landscape that will affect the timing, duration, and magnitude of runoff from the watershed and the amount of FC bacteria that would be released into the inlets. Evaluating future conditions is important to assess how changes in the land use and cover of the watershed will affect the water quality in the receiving waters of the inlets. A better understanding how these changes may impact future water quality may help to improve the development of water clean-up plans.

Uncertainty was addressed by simulating FC loading from a future expansive build-out scenario (Figure 4-19, Table 4-6). The change in land use and cover (LULC) was developed by the Kitsap County Northern Dyes Inlet Alternative Futures Planning Project (Folkerts, 2007a, b; Folkerts et al., 2007). The planning group developed future build-out scenarios for conservation and expansive growth for the watersheds located around Northern Dyes Inlet. The expansive growth build-out scenario was used to simulate future conditions to evaluate the effect of changing LULC on the water quality of Northern Dyes Inlet. This was accomplished by re-programming the watershed model HSPF with the projected changes in LULC to generate future flow conditions, recalculating the FC concentrations assigned to the streams and stormwater drainage basins in watershed based on the expansive build-out scenario, and then simulating the future loading conditions with CH3D-FC for the May 2004 storm event. The analysis assumes that the modeling system developed to represent present conditions is also applicable to future build-out and that the relationships between LULC and modeled flow and between LULC and predicted FC concentrations are still valid.

Because the percent coniferous forest cover (%CF) in the 100-meter buffer along streams was an important determinant in assigning FC concentrations in streams (May et al., 2005), and because there was no way to predict what the future stream buffer would be like, three future cases were simulated:

- Future expansive build-out with the same %CF in the 100-meter buffer as current conditions (S18 Same Buffer—“most likely”)
- Future expansive build-out with the %CF in the 100-meter buffer reduced in proportion to the increase in total impervious area (TIA) for the watershed (S19 Reduced Buffer—“worst case”)
- Future expansive build-out with the %CF in the 100-meter buffer set to 100% (S20 Full Buffer—“best case”).

These simulations were assumed to bracket potential future loading for the expansive build-out scenario, assuming all the other assumptions were also valid.

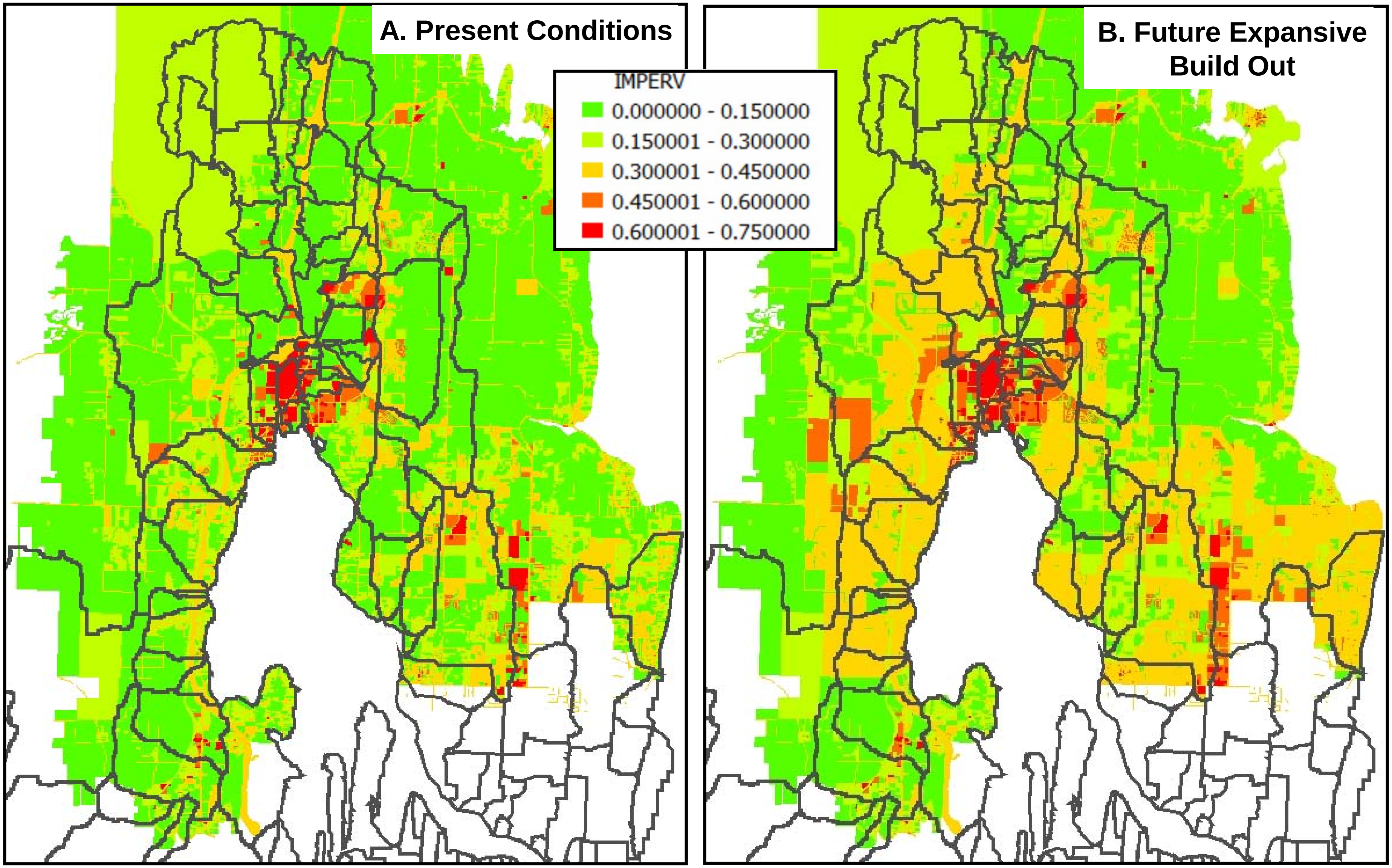


Figure 4-19. Fraction of impervious area in Northern Dyes Inlet for present conditions (A) and future expansive build-out (B).

Table 4-6. The percent of total impervious area (%TIA), coniferous forest (%CF), and herbaceous range land (%HL) calculated from the parcel map for the current conditions and futures based on the conservation and expansive build-out scenarios for the watersheds draining into Northern Dyes Inlet.

PourPoints			Current Conditions			Conservation Scenario			Expansive Build Out		
TYPE	DSN	Watershed Name	%TIA	%CF	%HL	%TIA	%CF	%HL	%TIA	%CF	%HL
stream	58	Barker Crk	17.4%	40.0%	1.9%	22.6%	35.3%	2.4%	23.9%	34.3%	2.7%
stream	65	Erlands Crk	8.7%	45.5%	1.0%	19.0%	38.3%	1.8%	28.6%	28.3%	2.2%
stream	66	Woods Cr.	11.1%	43.8%	1.6%	18.3%	37.8%	2.1%	31.0%	25.1%	2.3%
stream	67	Koch Crk	20.9%	38.3%	2.2%	35.3%	32.2%	1.9%	35.9%	31.6%	1.9%
stream	68	Crystal Crk	11.7%	43.1%	2.0%	14.3%	48.0%	4.2%	23.7%	39.9%	4.5%
stream	71	Jackson Park Crk	41.0%	29.0%	2.0%	42.2%	25.2%	2.5%	42.2%	25.2%	2.5%
stream	72	Stampede Crk	23.5%	35.0%	2.9%	30.7%	27.9%	3.5%	30.8%	27.8%	3.5%
stream	73	Pharman Crk	22.0%	36.9%	2.2%	26.7%	30.6%	3.0%	26.7%	30.6%	3.0%
stream	74	Illahee Crk	28.5%	33.1%	2.4%	35.5%	26.3%	2.7%	35.5%	26.3%	2.7%
stream	87	Chico Crk	10.6%	46.7%	1.1%	14.9%	43.8%	1.8%	15.5%	43.1%	1.8%
stream	92	Mosher Crk	22.3%	37.7%	2.2%	30.1%	29.3%	2.6%	30.1%	29.3%	2.6%
stream	94	Strawberry Crk	16.9%	40.7%	2.0%	26.9%	34.4%	2.2%	27.9%	33.5%	2.2%
stormwater	7	EB Pine Road	29.3%	35.0%	2.0%	32.9%	25.1%	2.3%	32.9%	25.1%	2.3%
stormwater	99	Silverdale Bayshore	28.9%	31.1%	2.4%	37.6%	23.8%	3.3%	37.6%	23.8%	3.3%
stormwater	104	Silverdale Bucklin Hill	21.9%	39.4%	2.5%	34.1%	30.8%	3.5%	34.1%	30.8%	3.5%
stormwater	136	Clear Creek	13.8%	49.2%	1.2%	19.8%	44.1%	1.6%	20.6%	43.5%	1.7%
stormwater	195	Tracyton Boat Dock	25.1%	36.0%	2.4%	32.6%	26.5%	2.3%	32.6%	26.5%	2.3%
stormwater	199	Tracyton Shoreline	30.0%	33.6%	2.3%	37.5%	23.8%	2.3%	37.5%	23.8%	2.3%
stormwater	216	Silverdale LMK002	31.2%	32.4%	2.0%	41.3%	27.0%	3.8%	41.3%	27.0%	3.8%
stormwater	217	Silverdale LMK001	26.7%	35.5%	2.4%	38.3%	28.4%	3.8%	38.3%	28.4%	3.8%
shore	21	EB North Illahee	24.0%	35.5%	2.6%	24.8%	35.5%	3.0%	24.8%	35.5%	3.0%
shore	23	Illahee (MESO-NW)	24.3%	37.5%	1.5%	29.7%	33.0%	2.2%	29.7%	33.0%	2.2%
shore	25	Earlands Point	21.3%	38.3%	2.3%	34.9%	28.9%	2.2%	34.9%	28.9%	2.2%
shore	95	Dyes Inlet Chico Bay N.	19.5%	38.5%	2.3%	25.3%	33.5%	2.5%	32.5%	26.5%	2.5%
shore	96	Dyes Inlet Chico Way	22.2%	37.5%	2.4%	29.8%	29.0%	2.2%	32.5%	26.1%	2.3%
shore	97	Chico Bay	23.8%	36.7%	2.2%	27.8%	33.1%	2.5%	28.2%	32.7%	2.5%
shore	98	Old Silverdale	25.7%	33.9%	2.7%	33.4%	26.4%	2.9%	33.2%	26.4%	2.9%
shore	100	Silverdale Tracyton Blvd	25.4%	34.1%	2.8%	34.3%	25.3%	2.7%	34.3%	25.3%	2.7%
shore	101	Dyes Inlet E Windy Pt	16.4%	40.8%	2.2%	28.1%	29.3%	2.6%	28.7%	28.6%	2.7%
shore	102	Tracyton Stampede Blvd	19.1%	38.3%	4.9%	25.2%	32.4%	2.6%	25.2%	32.4%	2.6%
shore	103	Tracyton Paxford Ln	15.7%	40.4%	2.2%	21.4%	34.4%	3.0%	21.4%	34.4%	3.0%
shore	137	Dyes Inlet West Cedar	23.2%	36.4%	2.7%	26.7%	33.9%	3.3%	29.4%	31.5%	3.0%

4.6.1 Future Conditions for Northern Dyes Inlet

Future landscape LULC scenarios were developed for the northern watersheds flowing into Dyes Inlet between Chico and Tracyton (Figure 4-19). The parcel maps representing the present condition, a conservation scenario, and an expansive build-out scenario were developed by the planning group and encoded into a geographical information system (GIS) database (Folkerts, 2007a, b; Folkerts et al., 2007). Only the present conditions and the future expansive build-out scenarios were used for the modeling exercise. The land uses from the parcel maps were used to calculate the resulting %TIA, %CF, and %HL within each watershed for the present conditions and expansive build-out scenarios (Table 4-6).

The future conditions for watersheds in Northern Dyes Inlet (Figure 4-19) were developed based on the area's parcel map (Folkerts, 2007b), but the watershed model and FC loading concentration model were based on the LULC determined from thematic mapper satellite imagery obtained for the study area in 1999 (CTC, 2001). To relate future conditions shown on Kitsap County's parcel map to the variables used in the FC model, the LULC classifications based on projected land use for each parcel were translated into the variables used in the HSPF model (Table 2-1). The change in %TIA (*Δ%TIA)* for the expansive build-out scenario (*FUTURE%TIA*) from the present %TIA (*PRESENT%TIA*) was used to calculate the percent change in each of the levels of development used in the cluster analysis based on the proportional weight (W_D) each development variable added to the calculation of %TIA (Table 4-7).

$$\%Future_D = \%Present_D \times \Delta\%TIA \times W_D \quad [17]$$

$$W_D = fTIA_D/1.7 \quad [18]$$

$$\Delta\%TIA = \frac{FUTURE\%TIA}{PRESENT\%TIA} \quad [19]$$

where: $\%Present_D$ and $\%Future_D$ are the percentage of developed land use *D* at present and in the future, respectively, $fTIA_D$ is the fraction of total impervious area for developed land use *D*, and 1.7 is the sum of the fraction of TIA for the developed land uses LD, MD, HD, and CI shown in Table 4-7.

Impervious area was increased by increasing the amount of development in proportion to the increase I TIA. For example, a 36% increase in TIA was defined as a 0.088 x 0.36 = 3.2% increase in LD residential, a 7.4% increase in MD residential, an 11.6% increase in HD Residential, and a 13.8% increase in CI development for the watershed. The %CF and %RL for the future scenarios were increased or decreased by the percent change from the present conditions. If the sum of the future LULC percentages used in the classification process summed to a value greater than one, then they were corrected by proportion to sum to one. The k-means cluster analysis was applied to the new (future) LULC variables (see Section 2.2) to cluster the future LULC into the five levels of development using the percentages of %CF, %HL, %LD, %MD, %HD, %CI, RD, SC/SL, and %CFB100 (see Table 2-5).

The watersheds within the Northern Dyes Inlet Planning Area analysis consisted of 12 shorelines, 9 stormwater outfalls, and 12 streams (Table 4-6). Based on the parcel data, the present condition %TIA ranged between 8 and 41% for all pour points and increased to 15 to 42% under the expansive build-out scenario (Table 4-6). The parcel-based estimates of the present %TIA for stream basins tended to be less than the Landsat based calculations, but they fell into the range obtained for the

Landsat clusters (Figure 4-20). Thus, the method of increasing the Landsat-derived cover by the percent change in the parcel-based present and future estimates was justified.

Table 4-7. Proportional weights for conversion of TIA to each level of development.

Land Use/Land Cover	Variable	Coefficients for calculating TIA (*fTIA*)	Weight (W_D)
Mixed Forest	MF	0.02	
Deciduous Forest	DF	0.03	
Coniferous Forest	CF	0.01	
Shrub & Brush	SB	0.05	
Agriculture	LDA	0.10	
Grassland/Turf/Pasture	HL	0.15	
Bare Ground	BL	0.25	
Developed Land Use			
Residential-Rural	LD	0.15	0.088235
Residential-Suburban	MD	0.35	0.205882
Residential-Urban	HD	0.55	0.323529
Commercial & Industrial	CI	0.65	0.382353
Sum of all Coefficients		2.31	1
Sum of Coefficients Associated with Developed Land Use		1.7	

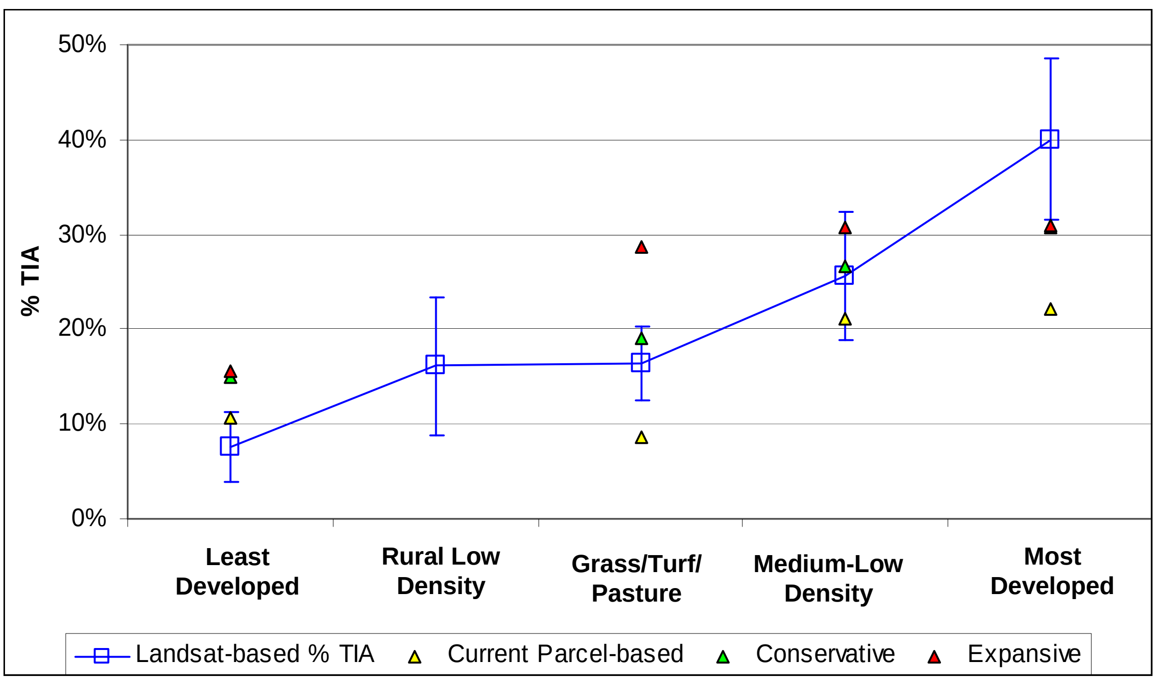


Figure 4-20. Relationship between percent total impervious area (%TIA) and the land use and cover clusters developed based on Landstat data (blue squares) and based on parcel data for present conditions (yellow triangles), conservation scenario (green triangles), and expansive build-out (red triangles) for the watersheds in the Northern Dyes Inlet Planning Area.

There was no way to predict what the future stream buffer (%CFB100), road density (RD), and fragmentation (SC/SL) would be like, so three future cases were simulated to bracket possible future conditions. The first scenario kept RD, SC/SL, and %CFB100 in their present state (Same Buffer). The second scenario increased RD and SC/SL by the increase in %TIA and decreased the %CFB100 within the riparian buffer by the same percent (Reduced Buffer). The third scenario set RD and SC/SL to 0 and %CFB100 to 100% (Full Buffer).

4.6.1.1 Future FC Loading Concentrations

A regression analysis of measured FC concentrations as a function of the discriminant scores derived from a discriminant analysis on the LULC clusters was used to estimate a unique geometric mean FC concentration for all subbasins (streams or shorelines) for future conditions:

$$\text{Geomean FC [cfu/100 ml]} = 24.112(\mathit{Score1}) + 91.73 \qquad [20]$$

where:

Score1 is the first discriminant score for the watershed sub-basin of interest

Note that this equation is different from EQU [1] (reported in May et al., 2005) because the landscape subwatershed boundaries were redefined and the cluster and discriminant analysis were recalculated for this exercise. The 25th and 75th percentiles of the FC distribution for each given cluster, based on present-day LULC data, were used to estimate bounds on the FC concentrations for all streams or shorelines categorized to be within that cluster using the future scenarios.

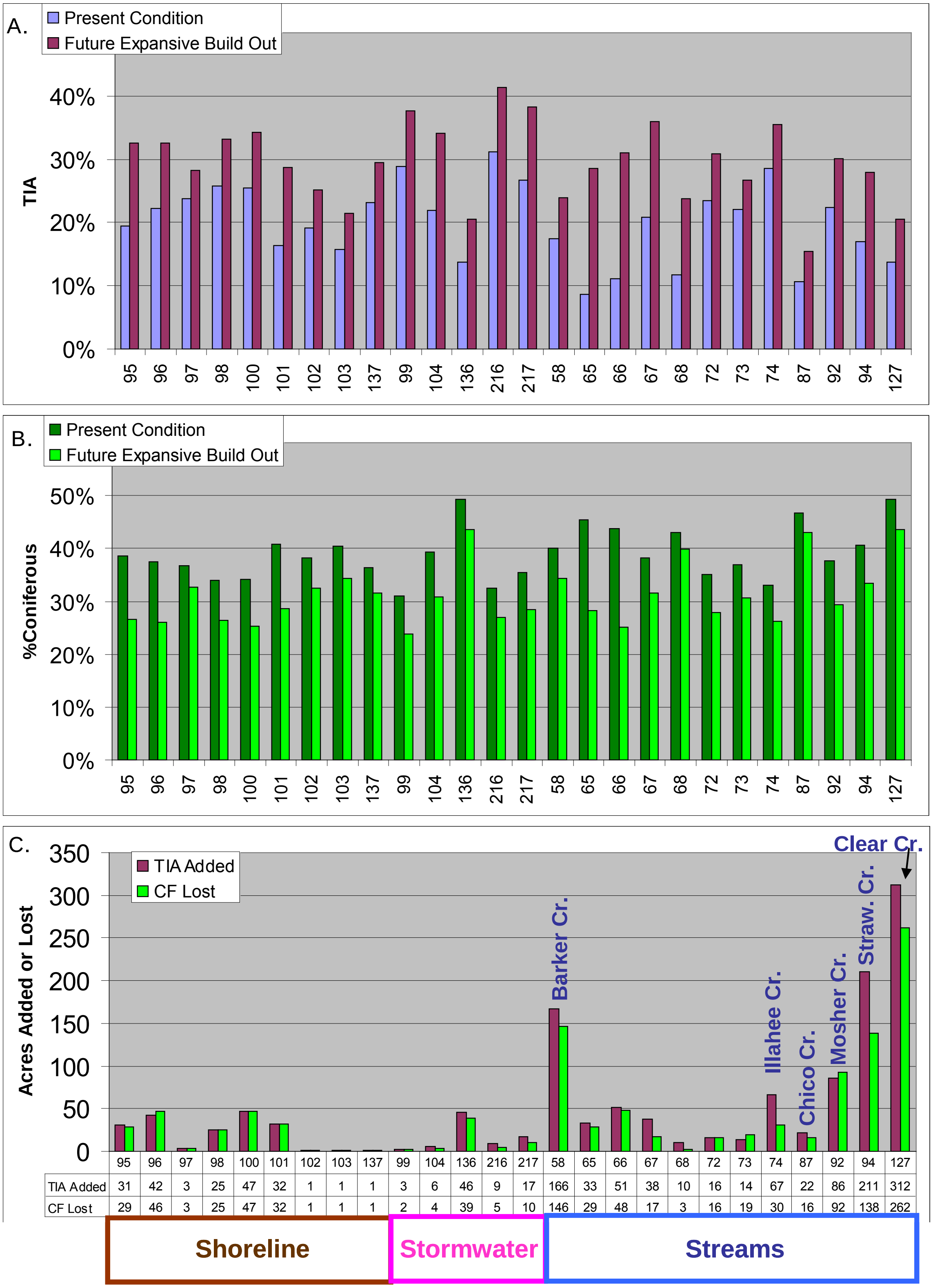
The future FC loading concentrations for the stormwater outfalls were determined from the classification assigned to the stormwater basins based on the level of developmental: urban, rural, and suburban (see Table 2-8). All the stormwater basins in the Northern Dyes Inlet Planning Area were classified as urban, except for the Tracyton Shoreline basin (DSN199), which was classified as shoreline for present conditions and suburban stormwater for the future expansive build-out. Under future conditions, the urban stormwater basins would have the same geomean FC loading concentration as present conditions (947 cfu/100 ml).

The predicted geomean FC loading concentrations for the same, reduced, and full buffer conditions for future expansive build-out for each watershed included in the Northern Dyes Inlet Alternative Futures Planning Project are summarized in Table 4-8. Only 4 out of the 12 streams and 1 shoreline basin (DSN199) were classified as Most Developed (Cluster 4) under present conditions. On average, the future build-out resulted in about a 49% increase in the %TIA, a 20% reduction in the %CF, and a 28% increase in %HL (Table 4-8). The future build-out increased TIA and HL but decreased CF to accommodate increased development, especially in the watersheds of Barker, Mosher, Strawberry, and Clear Creeks (Figure 4-21). Note that only the lower portion of Chico Creek was included in the alternative futures plan (see Figure 4-19), so there were only minor changes to the %TIA and %CF for all of Chico Creek.

Table 4-8. Predicted geomean FC loading concentrations for the same, reduced, and full buffer conditions for future expansive build-out as a function of the fraction of change in percent total impervious area (%TIA), coniferous forest (%CF), and herbaceous range land (%HL) for each watershed included in the Northern Dyes Inlet Alternative Futures Planning Project (Folkerts, 2007a, b; Folkerts et al., 2007).

Watershed				Present Condition		Expansive Buildout								
						Fraction of Change in LULC from Present			Buffer Condition					
									Same		Reduced		Full	
Model	DSN	NAME	TYPE	Cluster	Geomean cfu/100 ml	%TIA	%CF	%HL	Cluster	Geomean	Cluster	Geomean	Cluster	Geomean
BARKER	58	Barker Crk	stream	2	84.3	1.37	0.86	1.42	2	109.0	2	121.0	1	6.0
	72	Stampede Crk	stream	4	153.8	1.31	0.79	1.21	4	237.0	4	253.0	5	104.0
	73	Pharman Crk	stream	4	153.4	1.21	0.83	1.36	4	228.0	4	237.0	5	104.0
	92	Mosher Crk	stream	4	152.5	1.35	0.78	1.18	4	240.0	4	255.0	5	115.0
	100	Silverdale Tracyton Blvd	shore	5	153.7	1.35	0.74	0.96	4	200.0	4	195.0	5	113.0
	101	Dyes Inlet E. Windy Pt	shore	5	105.9	1.75	0.70	1.23	4	171.0	4	184.0	5	97.0
	102	Tracyton Stampede Blvd	shore	5	85.1	1.32	0.85	0.53	4	204.0	4	210.0	5	131.0
BST01	103	Tracyton Paxford Ln	shore	5	92.0	1.36	0.85	1.36	4	202.0	4	209.0	5	129.0
	7	EB Pine Road	stormwater	U	947.0	1.12	0.72	1.15	U	947.0	U	947.0	U	947.0
	195	Tracyton Boat Dock	stormwater	U	947.0	1.30	0.74	0.96	U	947.0	U	947.0	U	947.0
CHICO	25	Earlands Point	shore	5	144.0	1.64	0.75	0.96	4	214.0	4	212.0	5	120.0
	65	Erlands Crk	stream	3	23.7	3.29	0.62	2.20	3	87.0	3	225.0	3	9.5
	71	Jackson Park Crk	stream	5	140.0	1.03	0.87	1.25	4	200.0	4	202.0	1	44.0
	87	Lower Chico Crk	stream	1	36.6	1.46	0.92	1.64	3	36.0	3	57.0	1	11.0
	95	Dyes Inlet Chico Bay N.	shore	5	23.7	1.67	0.69	1.09	4	189.0	4	187.0	5	91.0
CLEAR	127	Clear Creek Stream	stream	5	96.6	1.49	0.88	1.42	4	144.0	4	168.0	5	59.0
	136	Clear Creek Stormwater	stormwater	U	947.0	1.49	0.88	1.42	U	947.0	U	947.0	U	947.0
LMK001	217	Silverdale LMK001	stormwater	U	947.0	1.43	0.80	1.58	U	947.0	U	947.0	U	947.0
LMK002	104	Silverdale Bucklin Hill	stormwater	U	947.0	1.56	0.78	1.40	U	947.0	U	947.0	U	947.0
	216	Silverdale LMK002	stormwater	U	947.0	1.32	0.83	1.90	U	947.0	U	947.0	U	947.0
SBC	21	EB North Illahee	shore	5	119.3	1.03	1.00	1.15	4	208.0	4	208.0	5	120.0
	23	Illahee (MESO-NW)	shore	3	23.7	1.22	0.88	1.47	3	129.0	3	129.0	1	32.0
	74	Illahee Crk	stream	3	23.7	1.25	0.79	1.13	3	128.0	3	134.0	1	26.0
	199	Tracyton Shoreline	shore/stormwater	4	90.2	1.25	0.71	1.00	S	140.0	S	140.0	S	140.0
STRAW	66	Woods Cr.	stream	5	36.3	2.79	0.57	1.44	5	149.0	4	207.0	1	43.0
	67	Koch Crk	stream	4	145.2	1.72	0.83	0.86	4	239.0	4	293.0	5	102.0
	68	Crystal Crk	stream	5	89.8	2.03	0.93	2.25	3	138.0	4	216.0	1	11.0
	94	Strawberry Crk	stream	5	82.7	1.65	0.82	1.10	4	168.0	4	198.0	1	59.0
	96	Dyes Inlet Chico Way	shore	5	126.3	1.46	0.70	0.96	4	208.0	4	207.0	5	110.0
	97	Chico Bay	shore	5	132.4	1.18	0.89	1.14	5	144.0	5	143.0	1	46.0
	98	Old Silverdale	shore	5	129.8	1.29	0.78	1.07	4	193.0	4	187.0	5	96.0
	99	Silverdale Bayshore	stormwater	U	947.0	1.30	0.77	1.38	U	947.0	U	947.0	U	947.0
	137	Dyes Inlet West Cedar	shore	5	142.5	1.27	0.87	1.11	4	204.0	4	202.0	5	104.0

Cluster Classification
1 – Least Developed; 2 – Rural Low Density; 3 – Grass/Turf/Pasture; 4 – Most Developed; 5 Medium-Low Density; S – Suburban Stormwater; U – Urban Stormwater



	95	96	97	98	100	101	102	103	137	99	104	136	216	217	58	65	66	67	68	72	73	74	87	92	94	127
TIA Added	31	42	3	25	47	32	1	1	1	3	6	46	9	17	166	33	51	38	10	16	14	67	22	86	211	312
CF Lost	29	46	3	25	47	32	1	1	1	2	4	39	5	10	146	29	48	17	3	16	19	30	16	92	138	262

Figure 4-21. Comparison between differences in %TIA (A) and %CF (B) for present and future expansive build-out conditions and the change in acres of TIA and CF (C) for future condition of each watershed in Northern Dyes Inlet (listed by DSN).

Geometric mean FC loading concentrations were calculated based on the present and future scenarios for shorelines, stormwater outfalls, and stream basins (Table 4-8). The geometric mean was based on the new scores derived from the projected LULC data, and lower and upper bounds were defined by the FC distributions derived from the present-day data set (May et al., 2005). For all future scenarios except the fully protected riparian buffer scenario, the classification of the LULC increased the first discriminant score (Root 1) towards the most developed centroid (Cluster 4). The discriminant scores for several of the shorelines and stream basins did not cluster around any particular centroid. Thus, the present number of clusters may not be appropriate for future landscape conditions. However, for the present exercise, except for Erlands Creek (DSN65) the results were generally close enough to a centroid to be classified. The 25th and 75th percentiles of the distance between an observation and the resulting class centroid were 1 and 3, respectively, for all scenarios. Erlands Creek had a distance of 9 from it's closest centroid. The next largest distance was 4.5 for Chico Creek. This suggests that the k-cluster regression method could predict future FC loading concentrations reasonably well.

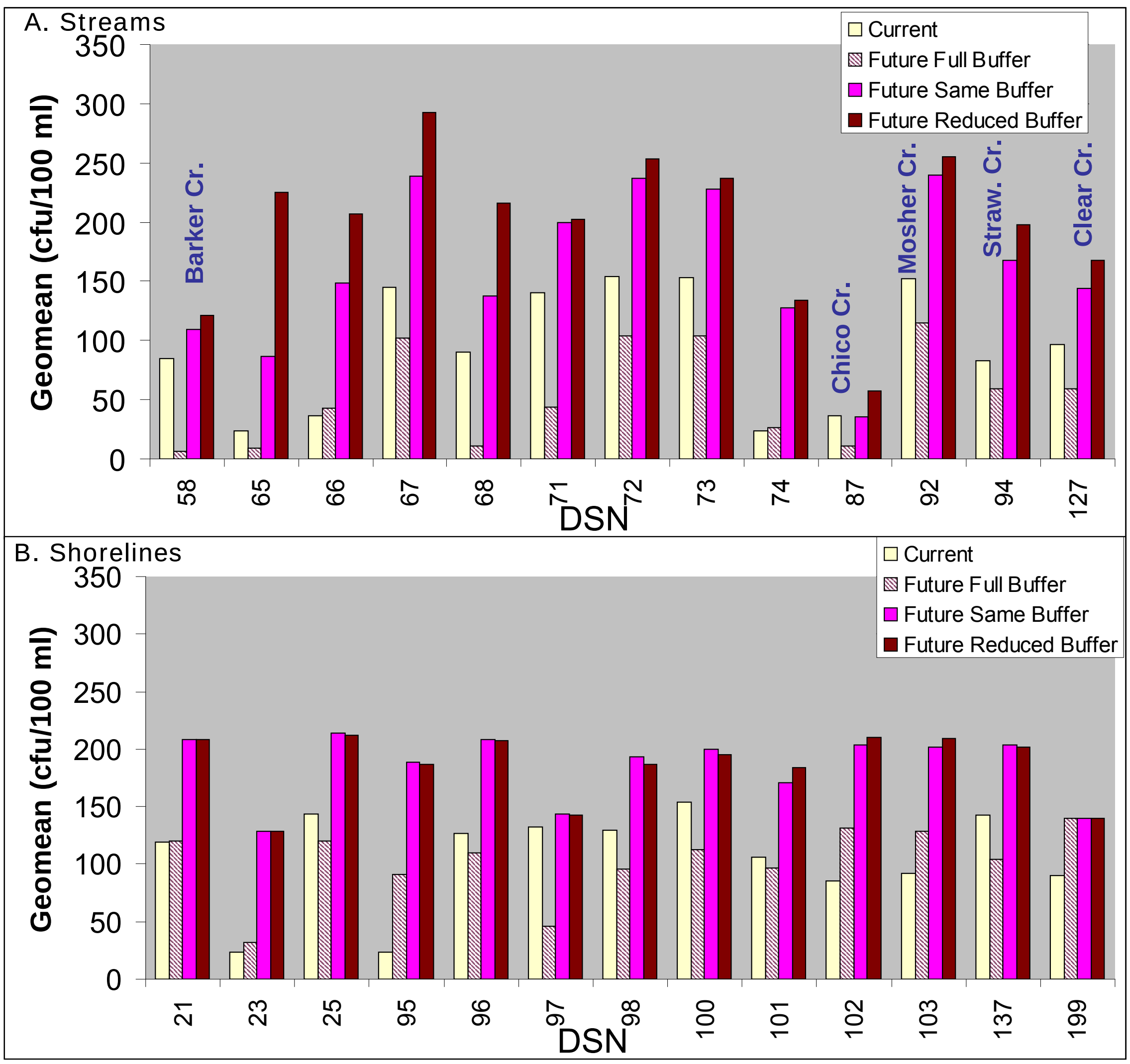


Figure 4-22. Present and future FC loading concentrations for streams (A) and shorelines (B) in the Northern Dyes Inlet Planning Area.

The expansive build-out scenario resulted in 6 of the 13 and 8 of the 13 streams to be grouped in the most developed cluster (Cluster 4) for the same and reduced buffer, respectively (Table 4-8). Interestingly, for the full buffer condition, none of the watersheds were assigned to the most developed cluster, and the FC loading concentrations were much reduced and in some cases even lower than present levels (Figure 4-22) because there was a strong inverse correlation between FC and the amount of CF in the 100-meter buffer around streams (May et al., 2005).

The future scenarios covered a range of possible FC loading concentrations extending between "best case" with the full buffer and "worst case" for the reduced buffer. The FC loading concentrations were higher for streams than for shorelines, and FC loading concentration in streams appeared to be more influenced by the buffer quality than the shorelines (Figure 4-22).

Assuming a 100-meter buffer around streams is probably unrealistic, but this was a result of the resolution of the original Landsat data that was based on 30-m pixels. Therefore, a 100-meter buffer was about the minimum buffer that could be evaluated with the available data set. The buffer quality appeared to be important in assigning cluster levels; however, the effect is not solely due to the buffer itself, but rather to the increase in CF, which is really a proxy for unaltered landscape. Larger areas of CF were highly correlated with much lower FC levels than altered landscapes in the empirical data set (May et al., 2005). The importance of the buffer also shows that the LULC in areas close to the stream (sampling location) is more important in terms of predicting FC concentrations than the land use and cover of the watershed as a whole.

4.6.1.2 Determining Future Flow Condition

Methodology

The other major factor affected by future development is in-stream flow. As was discussed for the watershed model development, care went into HSPF deployment so that the model could simulate future flows given future landscape conditions (see Section 2.1). For this exercise, the future LULC projected for the watershed was used to edit the UCI files for each of the models within the Northern Dyes Inlet Alternative Futures Planning Area (Figure 4-19, Table 4-8) to simulate the future flow regime.

A system of equations was used to transform the present condition LULC to the future expanded build-out using the relationships described below. The LULC variables used in the HSPF UCI file are shown in Figure 2-1. The UCI specifies the area in acres for each LULC class that is present in the watershed (DSN) being modeled (Table 4-8). An important calibration for each of the watersheds is the breakdown between the pervious and impervious portions of each of the developed land uses:

$$MD = pMD + iMD, \tag{21}$$
$$HD = pHD + iHD, \tag{22}$$
$$CI = pCI + iCI, \tag{23}$$
$$LD = pLD + iLD, \tag{24}$$

where the "p" denotes pervious area and "i" denotes impervious area for each of the developed land uses. The bolded variables shown in Table 4-9 were the LULC variables for which future targets could be defined based on the future alternatives (Table 4-6). To represent future conditions yet maintain the watershed model in a calibrated state, the ratios between the impervious and total land use for each class were kept constant for both present and future conditions:

$$iLD_{Present}/LD_{Present} = iLD_{Future}/LD_{Future} = a1 \quad [25]$$
$$iMD_{Present}/MD_{Present} = iMD_{Future}/MD_{Future} = a2 \quad [26]$$
$$iHD_{Present}/HD_{Present} = iHD_{Future}/HD_{Future} = a3 \quad [27]$$
$$iCI_{Present}/CI_{Present} = iCI_{Future}/CI_{Future} = a4 \quad [28]$$

Accordingly, future targets were defined for the future watershed condition based on the values identified in Table 4-6 for each watershed draining into Dyes Inlet. The HSPF model input files had to be modified for each of the upstream drainage basins as well and the targets were interpreted to represent the change to the overall basin. For example, Barker Creek consisted of five sub-basins, DSN61 → DSN60 → DSN59 → DSN62 → DSN58, so the LULC variables in each of the sub-basins had to be modified such that the overall watershed matched the future targets.

Table 4-9. Example of the schematic block from the HSPF UCI for lower Barker Creek (DSN58) showing the LULC variables depicted in the model and the breakdown between the pervious and impervious (red) cover defined for the developed land uses.

		SCHEMATIC					
		<-Volume->		<--Area-->	<-Volume->		<ML-> ***
		<Name>	x	<-factor->	<Name>	#	# ***
LULC	Var	*** statements below are for basin with id equal to 32 and mapping equal to 32					
Med. Dens. Res.	pMD	PERLND	89	50.602002	RCHRES	32	1
High Dens. Res.	pHD	PERLND	90	41.197581	RCHRES	32	1
Comm./Ind.	pCI	PERLND	91	40.647106	RCHRES	32	1
Acrgs/Rural Dev.	pLD	PERLND	92	0.0000000	RCHRES	32	1
Herb. Range Land	HL	PERLND	93	4.2255	RCHRES	32	1
Shrub & Brush RL	SB	PERLND	94	0.0000	RCHRES	32	1
Deciduous Forest	DF	PERLND	95	88.2908	RCHRES	32	1
Conif. Forest	CF	PERLND	96	75.3919	RCHRES	32	1
Mixed Forest	MF	PERLND	97	7.3390	RCHRES	32	1
Beaches	B	PERLND	98	0.0000	RCHRES	32	1
other barren lnd	BL	PERLND	99	0.0000	RCHRES	32	1
MED. DENS. RES.	iMD	IMPLND	91	6.7758674	RCHRES	32	2
HIG DENS. RES.	iHD	IMPLND	92	14.178735	RCHRES	32	2
COMM./IND.	iCI	IMPLND	93	42.306171	RCHRES	32	2
LOW DENS. RES.	iLD	IMPLND	94	0.0000000	RCHRES	32	2

It was assumed that the amount of land assigned to the levels of development would be proportional to the weights identified in Table 4-7 (W_D). For example, of all the developed land within a watershed, it was assumed that 9% would be LD, 21% would be MD, 32% HD, and 38% CI. This had the effect of creating an even distribution of land use classes and preventing unrealistic solutions (e.g., 100% CI land use), if possible. The known targets for the future conditions were the $\%TIA_{Future}$, $\%CF_{Future}$, $\%HL_{Future}$, the total area of the basin (Area–which remained constant), and the amount of other land uses (OT_{Future}) not specified, which was assumed to comprise a minimum of 2.5% of the total area in the watershed. These variables were used to calculate the future conditions (in acres):

$$TIA_{Future} = \%TIA_{Future} \times Area \quad [29]$$
$$HL_{Future} = \%HL_{Future} \times Area \quad [30]$$
$$CF_{Future} = \%CF_{Future} \times Area \quad [31]$$
$$OT_{Future} = 0.025 \times Area \quad [32]$$

Three solutions were developed using a system of equations to transform present-day land use to match the future targets:

Solution A: Seven unknowns, eight equations; constrained by area, future TIA, HL, and CF, and the proportion of developed land use classes.

$$LD + MD + HD + CI + HL + CF + OT = Area \quad [33]$$
$$a1LD + a2MD + a3HD + a4CI = TIA_{Future} \quad [34]$$
$$HL = HL_{Future} \quad [35]$$
$$+ CF = CF_{Future} \quad [36]$$
$$.38LD + .38MD + .38HD + (.38-1)CI = 0 \quad [37]$$
$$.32LD + .32MD + (.32-1)HD + .32CI = 0 \quad [38]$$
$$.21LD + (.21-1)MD + .21HD + .21CI = 0 \quad [39]$$
$$(.09-1)LD + .09MD + .09HD + .09CI = 0 \quad [40]$$

Solution B: Seven unknowns, nine equations; constrained by area, future TIA, HL, and CF, the proportion of developed land use classes, and the amount of other land uses.

$$LD + MD + HD + CI + HL + CF + OT = Area \quad [41]$$
$$a1LD + a2MD + a3HD + a4CI = TIA_{Future} \quad [42]$$
$$HL = HL_{Future} \quad [43]$$
$$+ CF = CF_{Future} \quad [44]$$
$$.38LD + .38MD + .38HD + (.38-1)CI = 0 \quad [45]$$
$$.32LD + .32MD + (.32-1)HD + .32CI = 0 \quad [46]$$
$$.21LD + (.21-1)MD + .21HD + .21CI = 0 \quad [47]$$
$$(.09-1)LD + .09MD + .09HD + .09CI = 0 \quad [48]$$
$$OT = OT_{Future} \quad [49]$$

Solution C: Seven unknowns, five equations; constrained by area, future TIA, HL, and CF, and the amount of other land uses.

$$LD + MD + HD + CI + HL + CF + OT = Area \quad [50]$$
$$a1LD + a2MD + a3HD + a4CI = TIA_{Future} \quad [51]$$
$$HL = HL_{Future} \quad [52]$$
$$+ CF = CF_{Future} \quad [53]$$
$$OT = OT_{Future} \quad [54]$$

The resulting matrices of coefficients were solved using MATLAB®. For example, the inputs for Barker Creek DSN58 using Solution B were as follows:

```
A_58b =[
    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
    0.1000    0.1900    0.3200    0.8282         0         0         0
         0         0         0         0    1.0000         0         0
         0         0         0         0         0    1.0000         0
    0.3824    0.3824    0.3824   -0.6176         0         0         0
    0.3235    0.3235   -0.6765    0.3235         0         0         0
    0.2059   -0.7941    0.2059    0.2059         0         0         0
   -0.9118    0.0882    0.0882    0.0882         0         0         0
         0         0         0         0         0         0    1.0000]

b_58b =[
  370.9500
   86.8900
    6.0000
   60.3100
         0
         0
         0
         0
    9.2700]
```

x = A_58b\b_58b [55]

```
x =

   28.2713
   55.7531
   82.2981
   85.1902
   16.9643
   71.2743
   20.2343
```

The variable A_58b is a matrix with the coefficients for the left side of the equations for Solution B, b_58b is a vector with the targets (right side of the equations), and the solution x was obtained by inversion, where x is a vector containing the acres of land for each land use variable in order of LD, MD, HD, CI, HL, CF, and OT ([55]). If a useable solution could not be obtained from Solution B, the constraints were relaxed and Solution A or C was used. If none of the solutions were usable, the land use characteristics were changed by hand using the goal-seek function in Microsoft Excel® until a usable solution was obtained.

A MATLAB® program was written to read in the UCI schematic data, calculate the future land uses, and output the new UCI schematic data for each of the watersheds included in the Northern Dyes Inlet Alternative Futures (Figure 4-19). A text editing program was then used to edit each of the UCI files and update the schematic blocks as necessary. No changes were made to schematic blocks that were not included in the futures analysis (e.g., upper Chico Creek). For certain watersheds in East Bremerton and Erlands Point where only a small portion of the watershed was included in the future alternative, the future changes were applied to the whole drainage basin because it was not possible to only change a small portion of the watershed in HSPF. These were DSN3 → DSN4 → DSN7, DSN74, DSN23, DSN21, DSN25, DSN195, and DSN199. The only changes made to the UCI files were the schematic blocks; all other input data remained unchanged.

The updated UCI files were then used to run the HSPF models to generate WDM files with the new flow data. Then the WDMutil program (USEPA, 2007) was used to extract the flow data needed to simulate the May 2004 storm event from the WDM files. Finally, the flow data and the FC loading concentration data for the same, reduced, and full buffer were reformatted into CH3D-FC input files to run the three future simulations.

4.6.1.3 Results of Flow Simulations

The present and future flows predicted by HSPF for watersheds in the Northern Dyes Inlet Planning Area for each watershed, including the original and future UCI and WDM files and example plots can be accessed on the distribution CD or via the internet (Table 1-1). In general, the future conditions resulted in much higher peak flows and lower base flows than present conditions for the May 2004 storm event. The effect was most pronounced for streams with the greatest increase in impervious area. Peak flows above 100 cfs were simulated for Clear Creek and Barker Creek (Figure 4-23), which had increases in TIA of 49% and 37%, respectively. Large increases in peak flows were also simulated for Illahee Creek (Figure 4-24A), a relatively undeveloped watershed in East Bremerton. In contrast, for Strawberry Creek, a moderately developed watershed in Silverdale, peak flows were only slightly increased for the future build- out scenario (Figure 4-24B).

The HSPF model assumed that the parameters selected during calibration for partitioning the annual precipitation across surface runoff (SURO), interflow runoff (IFWO), baseflow runoff (AGWO), total evapotranspiration (TAET), impervious surface runoff (I-SURO), and impervious surface total evapotranspiration (I-TAET) for each LULC would still be valid under the future conditions. Great care was taken to keep the impervious:pervious ratios constant for present and future conditions for each watershed and subwatershed, and none of the other model parameters were manipulated. Thus, the future condition was simulated while keeping the watersheds in a "calibrated state," only the mix of land use and cover was changed.

The future conditions were obtained by applying the projected development derived from the parcel map prepared by the alternative futures planning process. These changes are reflected in the parcel map for the watershed (Figure 4-19). However, the HSPF models were based on the Thematic Mapper™ data, which probably provides a more accurate measure of the actual LULC than what can be inferred from the parcel map. Any discrepancy introduced by "back-transforming" the parcel data was minimized by using the relative change to modify the HSPF schematic blocks. For example, the TIA calculated for Barker Creek from present and future parcel maps were 17 and 24%, respectively, resulting in a 37% increase in TIA for the future condition (Figure 4-19). The HSPF schematic block for present Barker Creek parcel data was programmed to represent (more accurately) 14.0% TIA for the watershed, so the schematic block was reprogrammed to result in a TIA of 19.2%, reflecting a 37% increase in TIA over the present condition to simulate the future build-out condition.

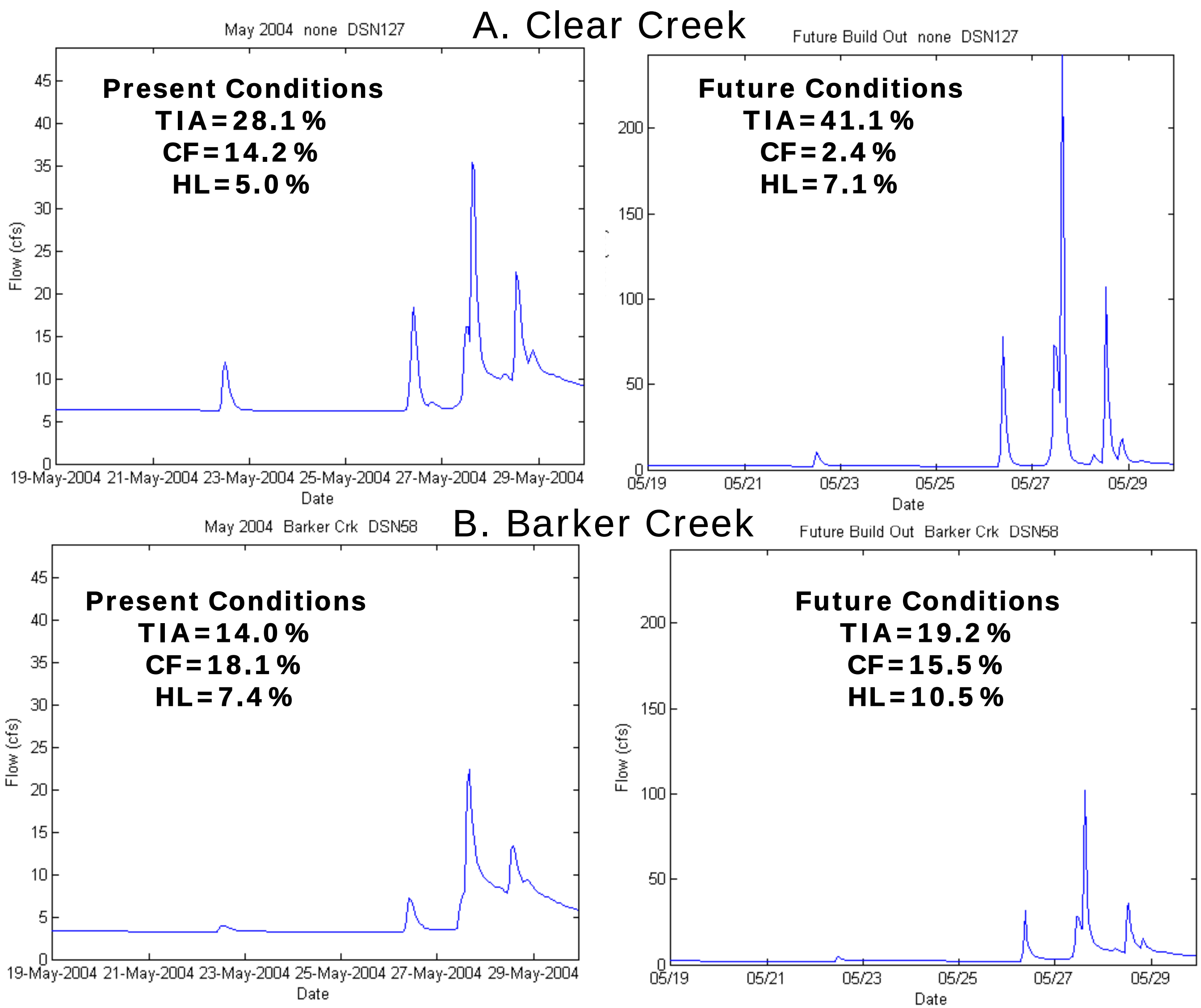


Figure 4-23. Present and future flows predicted for Clear Creek (A) and Barker Creek (B) for the May 2004 storm event.

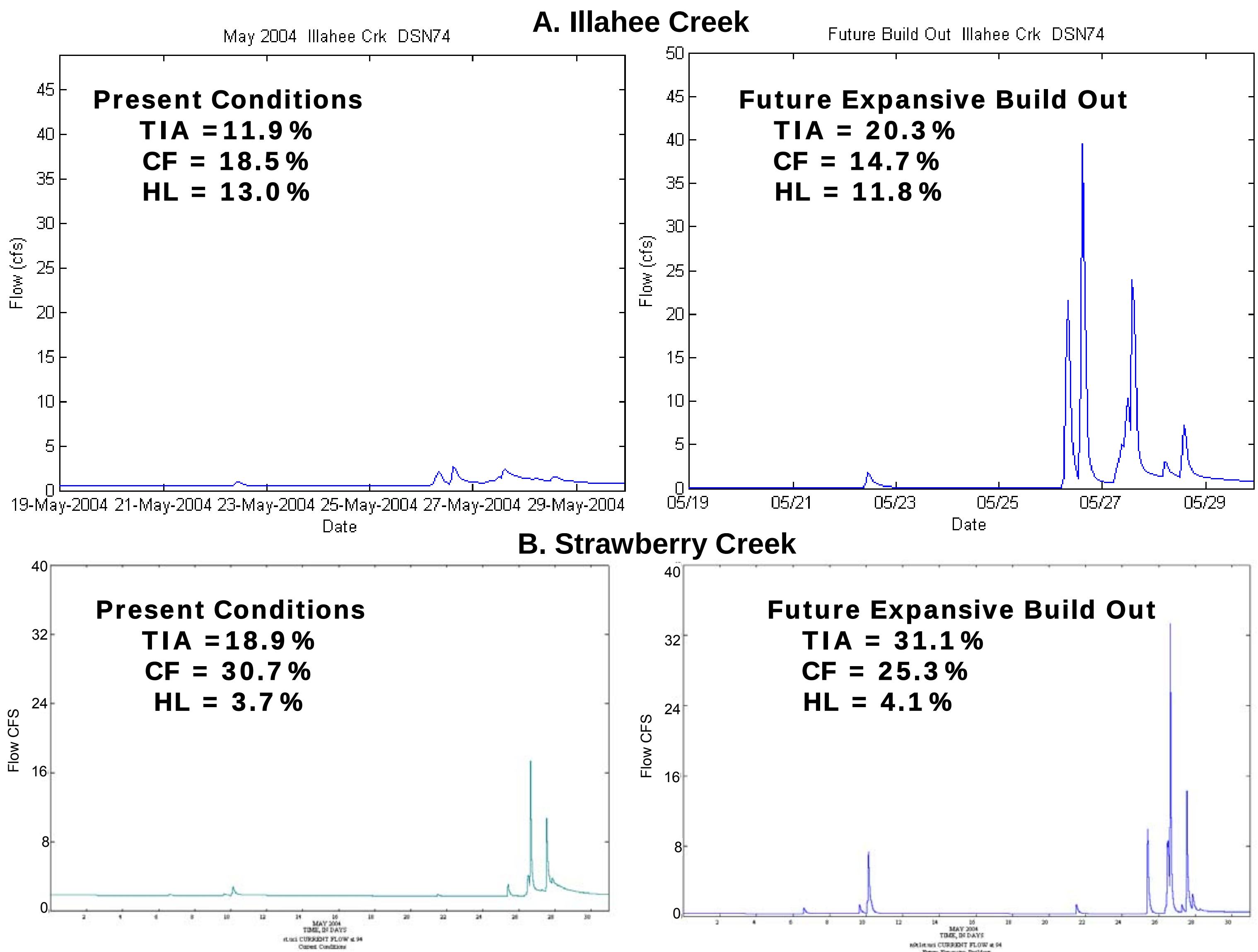


Figure 4-24. Present and future flows predicted for Illahee Creek (A) and Strawberry Creek (B) for the May 2004 storm event.

The flows generated from the May 2004 storm were strongly affected by increases in the impervious area in most of the watersheds simulated. A comparison between the results obtained for Illahee and Strawberry Creeks is very informative about the potential effects of future development. The Illahee Creek watershed is illustrative because it is one of the most natural drainage systems in the study area. Illahee Creek is located in East Bremerton, is about 800 acres in size, with most of the watershed undeveloped, and only about 10% of the watershed classified as urban/low development (Wright and Whitney, 2005). Only a small portion of the Illahee Creek watershed was included in the Northern Dyes Inlet Alternative Futures Planning process (Figure 4-19), but the relative change for that area was applied to the whole watershed to evaluate the effect on development within the entire watershed. This assumption was not unrealistic because here is interest in developing major portions of the watershed (Illahee Community Blog, 2008). The future scenario increased %TIA from 11.9 to 20.3%, %CF decreased from 18.5 to 14.7%, and %HL increased from 10.5 to 11.8%. These changes resulted in dramatic differences in the flows predicted in Illahee Creek for the May 2004 storm event (Figure 4-24). The striking difference between the flow hydrographs may be an indication of how sensitive relatively pristine streams are to development.

Located in Silverdale, the Strawberry Creek watershed is about 1850 acres in size, and a large portion of the watershed is developed (30% urban, 10% mixed use, 2.2% commercial, 6.8% rural, and 18.6% vacant, Wright and Whitney, 2005). Under present conditions, Strawberry Creek was modeled as 19% TIA, and future conditions resulted in 31% TIA. However, only minor increases in Strawberry Creek flows were simulated for the May 2004 storm under the future build-out scenario (Figure 4-24). These results suggest that once a watershed reaches a certain level of development, continued increases in development will have less of an impact on flow. Of course, each watershed is unique with a different mixture of soils, topography, land use, and land cover, but these results suggest that the effect of increasing development is nonlinear and will probably have a greater impact on streams and drainage areas with less development than areas that are already moderately or highly developed. Further, more detailed, analysis on the effect of different mixes of development and the interrelation between development and physical conditions and hydrologic process within the watershed are needed to fully understand the consequences of future development scenarios.

The level of development was very important for determining TIA, and there was a strong inverse correlation between TIA and the amount of CF (May et al., 2005). The estimates of TIA obtained from the TM and parcel data resulted in very similar values for the study area as a whole and for the major watersheds, although differences were noted for individual subwatersheds (Carlson, 2005). However, changes in TIA alone do not necessarily reflect the important changes on the ground, because there are virtually unlimited combinations of LULC variables that would result in the same amount of TIA.

The system of equations used to solve for the future LULC were derived to obtain an unbiased estimate of future conditions. Yet, there is considerable uncertainty about what mix of land uses that would actually occur in the future.

The results of the future watershed flow simulation were only evaluated for a single storm event, the 26 to 27 May 2004 storm event, which resulted in about 1.8 inches of rain in the Silverdale area. It was assumed that this was a typical storm event, which is justified based on the expected rainfall in the study area over the last 10 to 15 years (Halkola, 2005). Based on the assumption that relationships between flow and LULC developed from the present data set would be valid for future conditions, the watershed model could produce very plausible estimates of future flow for the single storm event evaluated.

4.6.2 Future FC Loading in Dyes Inlet

The simulation results for the future expansive build-out scenarios are available on the distribution CD or via the internet (Table 1-1). Due to the increased flows and higher FC loading concentrations projected for the future expanded build-out scenario, FC bacterial loading was greatly increased and resulted in model predictions of much higher FC concentrations in Northern Dyes Inlet than were simulated for the present conditions. In comparison to the present conditions simulated with the base model (geomean FC loading concentration), the future geomean FC concentration resulted in much higher FC concentrations for the May 2004 storm event with a marked increase in the frequency, magnitude, and duration of peaks that exceeded the FC water quality standard of 14 cfu/100 ml (Figure 4-25). It also caused greater penetration of FC bacteria plumes out into the inlet resulting in a much greater number of cells exceeding the standard (Figure 4-26, 19 cells exceed the standard for the future event; presently no cells exceeded the standard). The future geomean FC loading also generated plumes of FC bacteria that were higher than the 75th percentile FC loading for present conditions (Figure 4-26).

Manipulating the quality of the 100-m buffer, from full buffer with 100% CF coverage to a reduced buffer with %CF reduced by the increase in TIA, had relatively minor effects on the concentration and extent of FC plumes generated by the runoff (Figure 4-26). Each of the simulations had the same flow regime, because manipulating the buffer quality did not have any effect on hydrologic flows predicted by HSPF. This indicates that the future load was more influenced by the increases in flow projected by HSPF than by the increases in FC loading concentrations.

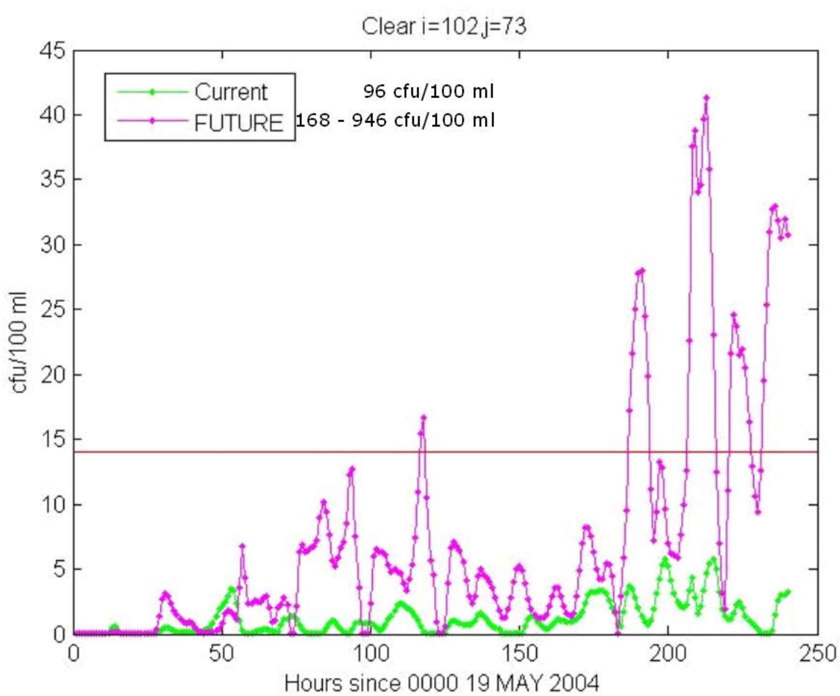


Figure 4-25. The effect of FC concentration predicted at the mouth of Clear Creek as a function of FC loading during the May 2004 storm event for present (green) and future expansive build-out (purple) LULC conditions.

FC cfu/100ml: May 28, 2004 08:00

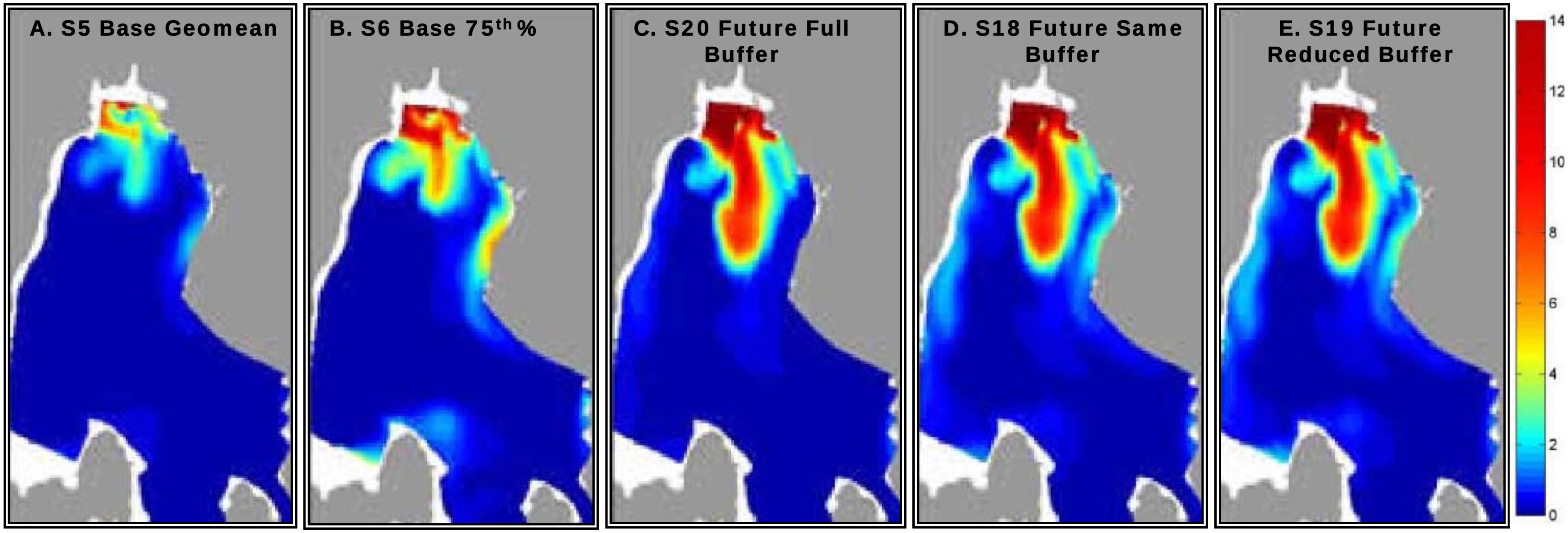


Figure 4-26. Comparison among plumes simulated for the May 2004 storm event with present LULC conditions and geomean (A) and 75th percentile (B) FC loadings and under future expansive buildout and geomean FC loading conditions with full (C), same (D), and reduced (E) stream buffer.

The futures analysis assumed that the modeling system developed to represent present conditions was also applicable to the future build-out and that the relationships between LULC and modeled flow and LULC and predicted FC concentrations would still be valid. Factors that could affect these relationships include low-impact development, increases in the efficiency of on-site treatment, repairs and improvements to the sewer infrastructure, identification and control of ongoing pollution sources, improvements to the stormwater infrastructure, and other actions that could reduce FC pollution.

The future simulation results showed that the expanded build-out would likely increase the frequency, magnitude, extent, and duration of FC levels exceeding water quality standards in the Northern Dyes Inlet.

4.6.3 Summary of Futures Analysis

The futures analysis assumed that the modeling system developed to represent present conditions was also applicable to future build-out and that the relationships between LULC and modeled flow and between LULC and predicted FC concentrations were still valid. Given that these current relationships are still applicable, the future simulations give a plausible indication of future threats associated with FC loading from the watershed.

The simulations of future conditions showed that expansive build-out would have a significant impact on FC loading and would increase the area of Dyes Inlet impacted by bacterial pollution. To the extent that the future simulations for Northern Dyes Inlet could be extrapolated to the rest of the study area, similar development levels would likely increase the frequency, magnitude, extent, and duration of FC levels exceeding water quality standards through out the watershed.

The uncertainty associated with the futures analysis lessens the confidence that can be placed in the results of the future predictions because there is no way of knowing how future development will play out. However, and more importantly, the futures analysis allowed the possible impacts from increased FC loading from a combination of increased concentration and increased flow to be evaluated. While it is not possible to know what the future has in store, it is likely that future impacts would be “more of the same” and any actions that effectively eliminate or reduce current problems would also be effective in addressing future problems. Such actions may include the initiatives taken by municipalities to comply with the National Pollutant Discharge Elimination System (NPDES) Phase II municipal stormwater requirements, including illicit discharge detection and removal, increased street sweeping, stormwater system maintenance improvements, and public education and outreach programs (see May et al., 2005 for recommendations for reducing FC pollution).

5. TDML SIMULATIONS

We used the verified HSPF/CH3D-FC model to simulate specific scenarios for the TMDL. First, the "actual conditions" for WY2003 were simulated using the 91 x 96 grid by setting the FC loading concentration to the geomean (the "best estimate" of actual conditions) and assessing compliance with marine water quality standards. Model output was processed to obtain a 30-day moving average of the daily maximum, which was compared to 14 cfu/100 ml to identify critical conditions and canary nodes that exceeded Part I of the standard (S11 in Table 4-1). Two simulations were conducted to calculate waste load and load allocations for streams, stormwater outfalls, and WWTPs. Part I of the standard was evaluated by setting the streams and stormwater outfalls to 100 cfu/100 ml and WWTPs to 200 cfu/100 ml (S12 100/200 in Table 4-1). Waste loads and load allocations for Part II of the standard were simulated by setting the streams and stormwater outfalls to 200 cfu/100 ml and WWTPs to 400 cfu/100 ml (S13 200/400 in Table 4-1). For Part I, the daily max from the simula-tions for each grid within the canary nodes was used to calculate a 30-day moving average to compare to the water quality standard of 14 cfu/100 ml. For Part II, the daily max from the simula-tions for each grid within the canary nodes was used to calculate a 30-day moving average of the 90th percentile to compare to the water quality standard of 43 cfu/100 ml. The details of the simulations and the results obtained are reported below.

5.1 WY2003 Critical Conditions

Actual conditions were simulated by setting the FC loading to the 50th percentile (geometric mean) estimated for WY2003 and comparing the results to the water quality standards of 14 cfu/100 ml (Part I: geomean) and 43 cfu/100 (Part II: 90th percentile). All streams, stormwater outfalls, and WWTP were set to "actual conditions" (same settings used for simulation S10) to simulate total FC loading from all sources for WY2003 using the 91 x 96 grid (S11). The daily max from the simulation (max(FC_d)) is the simulated maximum daily FC concentration from d = 1 October 2002 to 29 September 2003 (364 days). The daily maximum was used to calculate a 30-day moving geomean to compare to Part I of the standard (14 cfu/100 ml) and a 30-day moving 90th percentile to compare to Part II of the standard (43 cfu/100 ml):

$$\log(m30day_d + 1) = \frac{\sum_{i=d-29}^{d} \max(\log(FC_i + 1))}{30} \qquad [56]$$

$$m30day_d = 10^{(\log(m30day_d)} - 1 \qquad [57]$$

= Moving 30-day geomean of daily max FC for each node from 30 October 2002 to 29 September 2003 (d = 30 to 364 days)

and the 90th percentile was calculated as mean + 1.28(*stdev*), where *stdev* was the standard deviation of the data in log space.

$$\log(m30day90_d + 1) = \frac{\sum_{i=d-29}^{d} \max(\log(FC_i + 1))}{30} + 1.28(stdev) \qquad [58]$$

$$m30day90_d = 10^{(\log m30day90_d)} - 1 \qquad [59]$$

The number of days the standard was exceeded ($NDAY_{14}$, $NDAY_{43}$) was calculated as:

$$EX14 = \text{For } i = 30{,}364\text{; if } m30day_i \geq 14\text{; } EX14_i = 1\text{, else } EX14_i = 0 \text{ end;} \qquad [60]$$

$$NDAY_{14} = \sum_{i=1}^{334} EX_{14} \qquad [61]$$

$$EX43 = \text{For i = 30,364; if m30day90}_i \geq 43\text{; EX43}_i = 1\text{, else EX43}_i\text{=0 end;} \qquad 62]$$

$$NDAY_{43} = \sum_{i=1}^{334} EX_{43} \qquad [63]$$

The 30-day moving geometric mean was averaged for the highest 1/2/3/4/6/9 grid cells of each canary node for the surface node (*gridAVG_surf*) and depth-averaged nodes (*gridAVG_depthavg*). If the standard was exceeded (*EX14* = 1 or *EX43* = 1), the fraction reduction needed was calculated for both surface and depth averaged grids as

$$fc\_target\_surf = 1 - 14/gridAVG\_surf \qquad [64]$$

$$fc\_target\_depthavg = 1 - 14/gridAVG\_depthavg \qquad [65]$$

$$fc\_target90\_surf = 1 - 43/gridAVG\_surf \qquad [66]$$

$$fc\_target90\_depthavg = 1 - 43/gridAVG\_depthavg \qquad [67]$$

The simulation results for S11 (WY2003 actual conditions) using the 91 x 96 grid are summarized below; supplemental information including all the results of the S11 simulation files is available on the distribution CD or via the internet (Table 1-1). The simulation results (Table 5-1) showed that Part I of the standard (14 cfu/100 ml) was exceeded at the canary nodes for Clear (Figure 5-1), Gorst (Figure 5-2), and Blackjack Creeks (Figure 5-3); none of the canary nodes exceeded Part II of the standard (43 cfu/100 ml). The 30-day moving geomean exceeded Part I of the standard for 25 days in two nodes and 6 days in a third node at Clear Creek, 50 days in one node at Gorst Creek, and 4 days in one node at Blackjack Creek (Table 5-1). Based on the maximum 30-day geomean, the current FC loading would need to be reduced by 15, 25.7, and 4.1% to meet standards in the nearshore areas of Clear/Stawberry, Gorst, and Blackjack Creeks, respectively (Table 5-1). All the other canary nodes met Part I and Part II of the standard for the WY2003 simulation using actual loading conditions.

Table 5-1. Summary of results for canary nodes that exceeded standards for the simulation of actual conditions using estimates of present-day loading (S11).

Group	Daily Max				30-Day Moving GeoMean of Daily Max				Number of Days GeoMean Exceeded Standard	
	Average		Maximum		Average		Maximum			
	surface	depth-avg	surface	depth-avg	surface	depth-avg	surface	depth-avg	surface	depth-avg
03-Dyes-Clear-Cr-										
grid 1	3.4	3.4	41.0	41.0	2.8	2.8	9.1	9.1	0	0
grid 2	2.5	2.5	40.0	40.0	1.8	1.8	8.8	8.8	0	0
grid 3	2.4	2.4	40.0	40.0	1.9	1.9	8.7	8.7	0	0
grid 4	7.9	7.9	50.0	50.0	7.2	7.2	16.5	16.5	25	25
grid 5	4.2	4.2	51.0	51.0	2.9	2.9	13.4	13.4	0	0
grid 6	4.8	4.8	53.0	53.0	3.8	3.8	14.9	14.9	6	6
grid 7	7.5	7.5	45.0	45.0	7.1	7.1	16.5	16.5	25	25
grid 8	4.8	4.8	35.0	35.0	4.0	4.0	8.8	8.8	0	0
grid 9	4.6	4.6	33.0	33.0	4.1	4.1	8.2	8.2	0	0

	Average of highest 1/3/4/6/9 grid cells 30-Day Moving GeoMean of Daily Max				03-Dyes-Clear-Cr-	
	Average		Maximum		Reduction Needed	
	surface	depth-avg	surface	depth-avg	Average	Maximum
max grid	7.2	7.2	16.5	16.5	OK	15.2%
avg of 2 grids	7.1	7.1	16.5	16.5	OK	15.2%
avg of 3 girds	6.1	6.1	13.5	13.5	Meets Standard	
avg of 4 girds	5.6	5.6	11.4	11.4		
avg of 6 girds	4.8	4.8	12.1	12.1		
avg of 9 girds	3.9	3.9	10.9	10.9		

Group	Daily Max				30-Day Moving GeoMean of Daily Max				Number of Days GeoMean Exceeded Standard	
	Average		Maximum		Average		Maximum			
	surface	depth-avg	surface	depth-avg	surface	depth-avg	surface	depth-avg	surface	depth-avg
43-Sin-Gorst-Creek										
grid 1	9.8	9.8	38.0	38.0	9.4	9.4	18.6	18.6	50	50
grid 2	5.4	5.4	35.0	35.0	5.2	5.2	11.3	11.3	0	0
grid 3	4.0	4.0	30.0	30.0	3.9	3.9	8.4	8.4	0	0
grid 4	3.1	3.1	19.0	19.0	3.0	3.0	6.9	6.9	0	0
grid 5	2.1	2.1	14.0	14.0	2.1	2.1	5.7	5.7	0	0
grid 6	4.4	4.4	26.0	26.0	4.4	4.4	11.1	11.1	0	0
grid 7	2.4	2.4	28.0	28.0	2.3	2.3	5.6	5.6	0	0
grid 8	2.6	2.6	35.0	35.0	2.4	2.4	6.1	6.1	0	0
grid 9	3.6	3.6	38.0	38.0	2.6	2.6	7.7	7.7	0	0

	Average of highest 1/3/4/6/9 grid cells 30-Day Moving GeoMean of Daily Max				43-Sin-Gorst-Creek	
	Average		Maximum		Reduction Needed	
	surface	depth-avg	surface	depth-avg	Average	Maximum
max grid	9.4	9.4	18.6	18.6	OK	24.7%
avg of 2 grids	7.3	7.3	15.0	15.0	OK	6.4%
avg of 3 girds	6.3	6.3	13.7	13.7	Meets Standard	
avg of 4 girds	5.7	5.7	12.3	12.3		
avg of 6 girds	4.8	4.8	10.6	10.6		
avg of 9 girds	3.9	3.9	9.0	9.0		

Table 5-1 (continued).

Group	Daily Max				30-Day Moving GeoMean of Daily Max				Number of Days GeoMean Exceeded Standard	
	Average		Maximum		Average		Maximum			
	surface	depth-avg	surface	depth-avg	surface	depth-avg	surface	depth-avg	surface	depth-avg
50-SinPO-BlackJ-Cr										
grid 1	1.6	0.6	10	4	1.6	0.6	3.9	1.7	0	0
grid 2	1.9	0.8	12	4	1.8	0.7	4.4	1.9	0	0
grid 3	1.4	1.4	15	15	1.2	1.2	2.6	2.6	0	0
grid 4	2.9	2.9	19	19	2.7	2.7	5.7	5.7	0	0
grid 5	4.5	4.5	28	28	4.4	4.4	8.7	8.7	0	0
grid 6	3.3	3.3	29	29	3.2	3.2	6.5	6.5	0	0
grid 7	7.1	7.1	50	50	6.8	6.8	14.6	14.6	4	4
grid 8	2.8	2.8	24	24	2.7	2.7	5.8	5.8	0	0
grid 9	2.2	2.2	12	12	2.0	2.0	4.7	4.7	0	0

	Average of highest 1/3/4/6/9 grid cells 30-Day Moving GeoMean of Daily Max				50-SinPO-BlackJ-Cr	
					Reduction Needed	
	Average		Maximum		Average	Maximum
	surface	depth-avg	surface	depth-avg		
max grid	6.8	6.8	14.6	14.6	OK	4.1%
avg of 2 grids	5.6	5.6	11.7	11.7	Meets Standard	
avg of 3 girds	4.8	4.8	9.9	9.9		
avg of 4 girds	4.3	4.3	8.9	8.9		
avg of 6 girds	3.6	3.6	7.7	7.7		
avg of 9 girds	2.9	2.7	6.3	5.8		

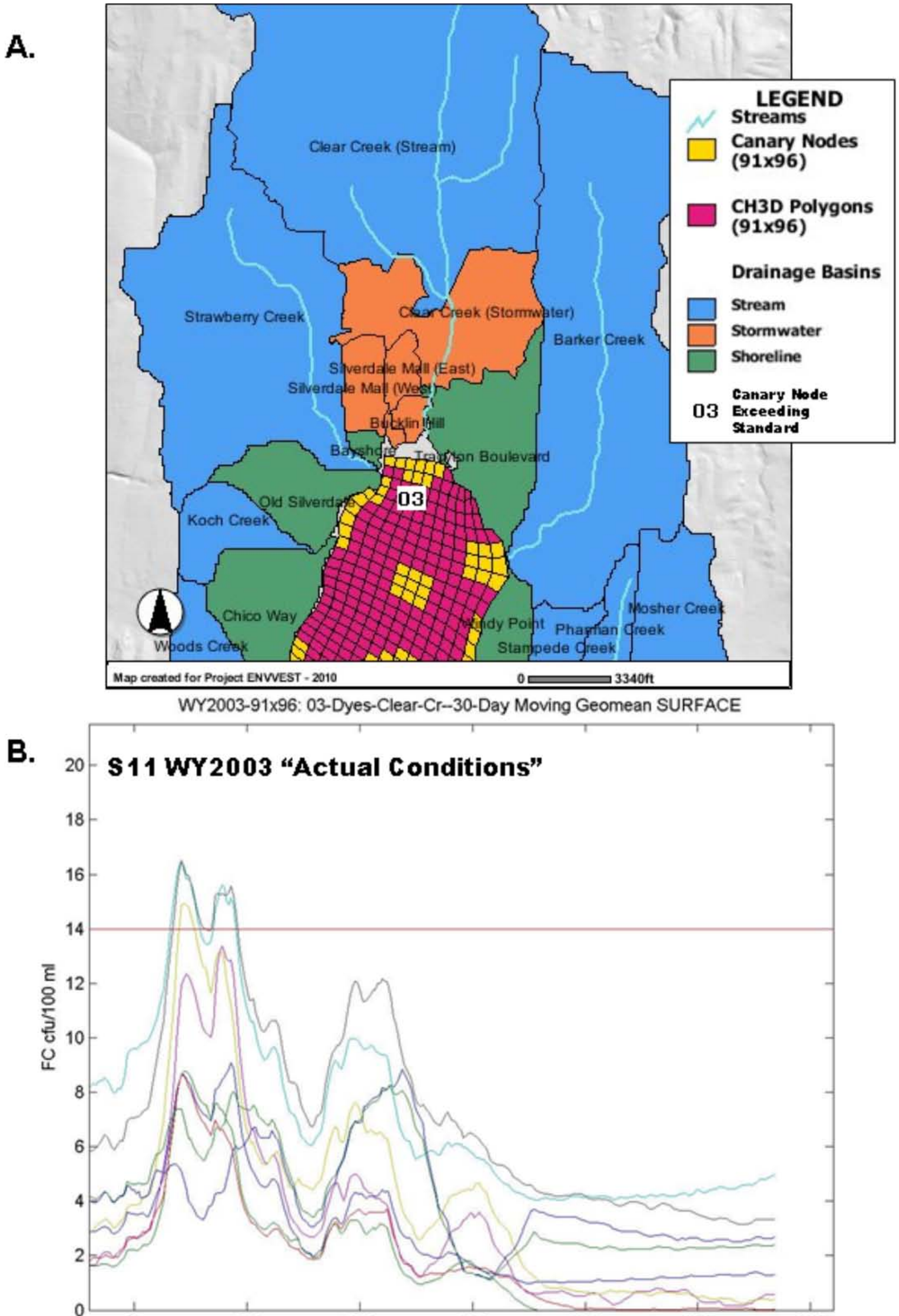
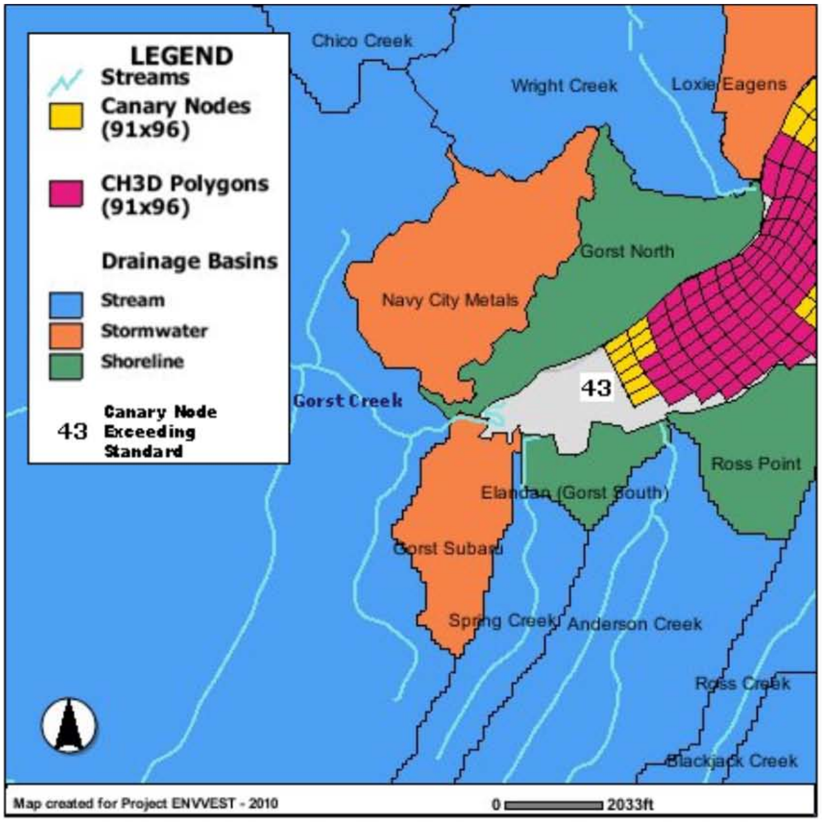


Figure 5-1. Location of Canary Node 03-Dyes-Clear-Cr (A) and simulated 30-day moving geomean for the surface grid cells (B) from simulation scenario S11 WY2003 "Actual Conditions."

A.



B.

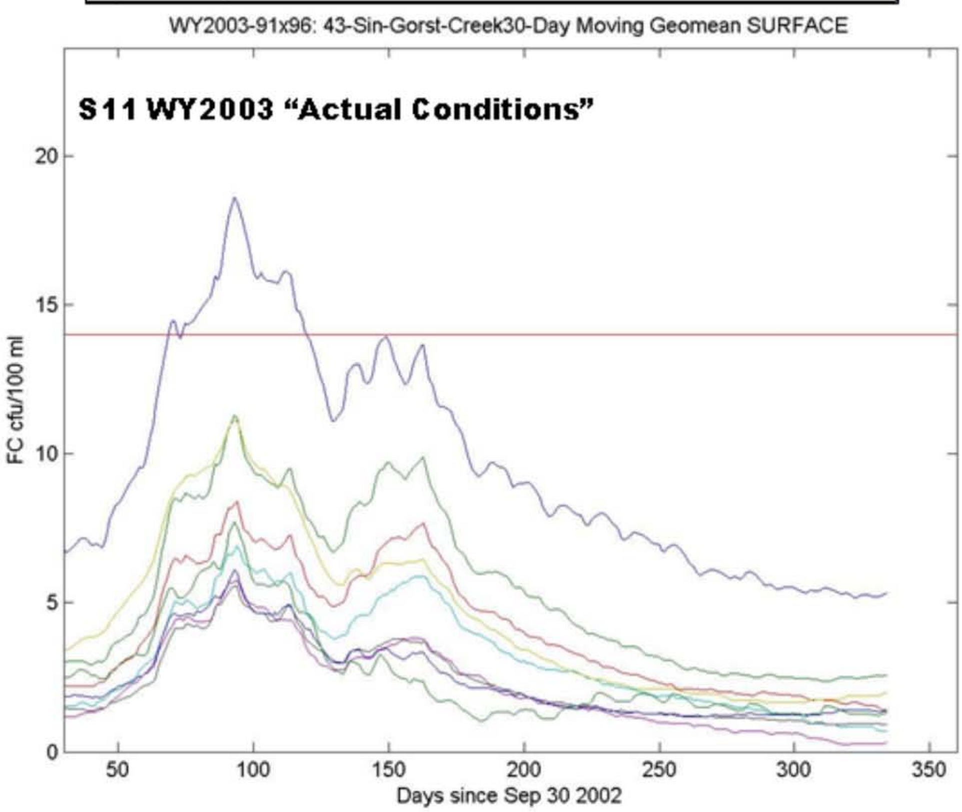


Figure 5-2. Location of Canary Node 43-Sin-Gorst-Creek (A) and simulated 30-day moving geomean for the surface grid cells (B) from simulation scenario S11 WY2003 "Actual Conditions."

A.

B.

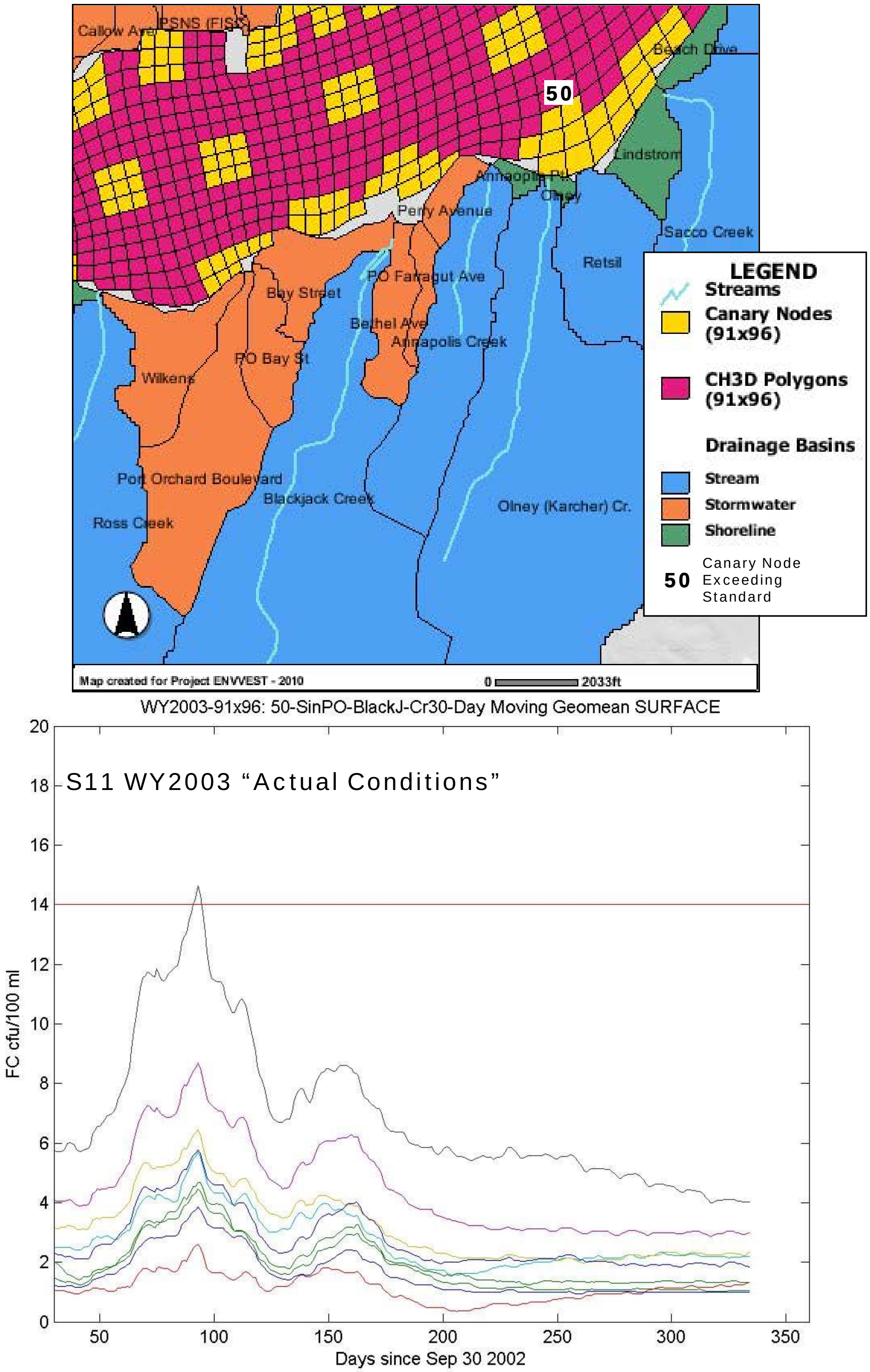


Figure 5-3. Location of Canary Node 50-SinPO-BlackJ-Cr (A) and simulated 30-day moving geomean for the surface grid cells (B) from simulation scenario S11 WY2003 “Actual Conditions.”

5.2 WY2003 100/200

The simulation results for S12 (TMDL 100/200) using the 91 x 96 grid are summarized below; supplemental information including all the S12 simulation results are available on the distribution CD or via the internet (Table 1-1). For simulation S12, all streams and stormwater outfalls were set to 100 cfu/100 ml, and all WWTPs[13] were set to 200 cfu/100 ml. The daily maximum was used to calculate a 30-day moving average to compare to Part I of the standard (14 cfu/100 ml) using the equations described above. The results for the TMDL 100/200 simulation (Table 5-2) showed that Part I of the standard (14 cfu/100 ml) was exceeded at canary nodes located at Gorst Creek (Figure 5-4), Blackjack Creek (Figure 5-5), and near the Bremerton WWTP outfall (Figure 5-6, Figure 5-7).

For Gorst Creek, the grids exceeded Part I of the standard for 3 to 334 days, and a reduction of 14.7 to 77% would be required to meet water quality standards (Table 5-2). The canary node located near Bremerton's Sinclair WWTP outfall (SN03) exceeded the standard for 171 and 34 days in one surface and depth-averaged grid, respectively, and the canary node at the mouth of Blackjack Creek exceeded the standard at two grids, one for 107 days and the other for 21 days (Table 5-2). Based on these results, the simulated FC loads would need to be reduced by 8.6 to 45% to meet the standard at SN03, and 2 to 49.7% to meet the standard at Blackjack Creek (Table 5-2). All the other canary nodes met Part I of the standard for the WY2003 simulation using the 100/200 loading conditions.

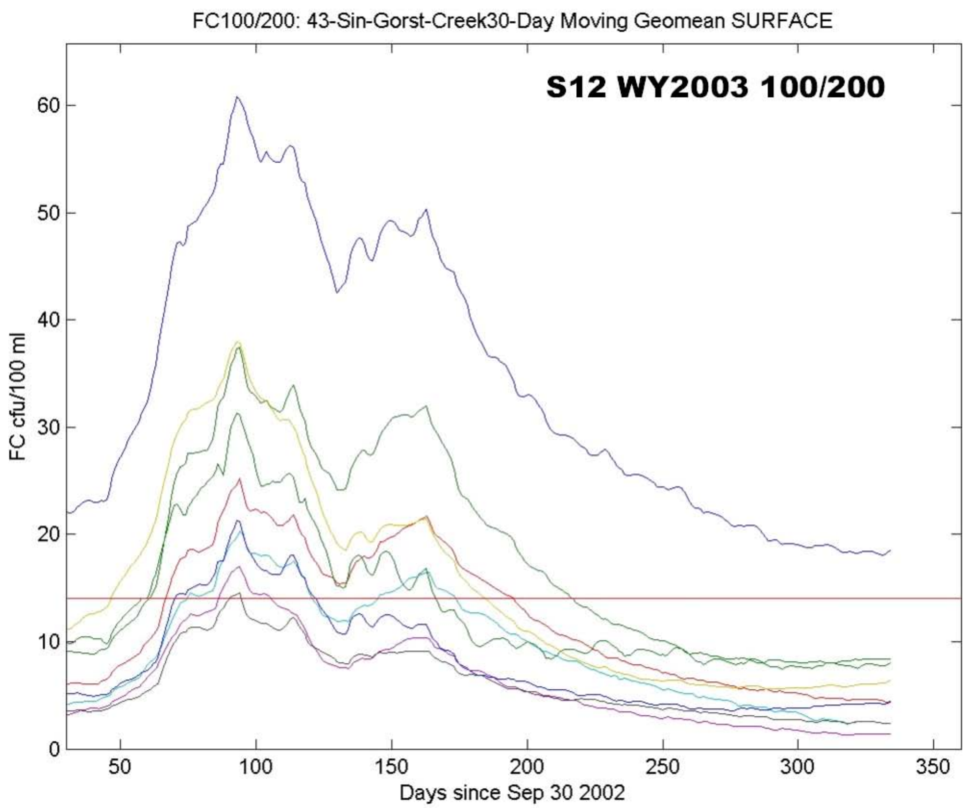


Figure 5-4. The simulated 30-day moving geomean of the daily maximum simulated for the Gorst Creek canary nodes from the TMDL 100/200 simulation. See Figure 5-2 for canary node location.

[13] No discharges were programmed for the Bremerton Eastside Treatment Facility because the facility is designed to come online in response to storm events to treat combined sewer overflows (City of Bremerton, 2005; 2007).

Table 5-2. Summary of results for canary nodes that exceeded standards for the simulation of TMDL 100/200 (S12).

Group	Daily Max				30-Day Moving GeoMean of Daily Max				Number of Days GeoMean Exceeded Standard	
	Average		Maximum		Average		Maximum			
	surface	depth-avg	surface	depth-avg	surface	depth-avg	surface	depth-avg	surface	depth-avg
43-Sin-Gorst-Creek										
grid 1	33.1	33.1	99.0	99.0	33.1	33.1	60.8	60.8	334	334
grid 2	17.5	17.5	100.0	100.0	17.2	17.2	37.4	37.4	156	156
grid 3	11.7	11.7	82.0	82.0	11.6	11.6	25.2	25.2	129	129
grid 4	8.8	8.8	49.0	49.0	8.8	8.8	20.3	20.3	75	75
grid 5	6.0	6.0	44.0	44.0	6.0	6.0	17.0	17.0	19	19
grid 6	14.6	14.6	84.0	84.0	14.7	14.7	37.9	37.9	138	138
grid 7	6.2	6.2	75.0	75.0	5.9	5.9	14.5	14.5	4	4
grid 8	8.7	8.7	99.0	99.0	7.9	7.9	21.3	21.3	52	52
grid 9	15.4	15.4	101.0	101.0	13.1	13.1	31.3	31.3	107	107
					Average of highest 1/2/3/4/6/9 grid cells				43-Sin-Gorst-Creek	
					30-Day Moving GeoMean of Daily Max					
					Average		Maximum		Reduction Needed	
					surface	depth-avg	surface	depth-avg	Average	Maximum
				max grid	33.1	33.1	60.8	60.8	**57.7%**	**77.0%**
				avg of 2 girds	25.2	25.2	49.1	49.1	**44.4%**	**71.5%**
				avg of 3 girds	21.7	21.7	45.4	45.4	**35.4%**	**69.1%**
				avg of 4 girds	19.5	19.5	41.8	41.8	**28.2%**	**66.5%**
				avg of 6 girds	16.4	16.4	35.4	35.4	**14.7%**	**60.5%**
				avg of 9 girds	13.1	13.1	29.5	29.5	**OK**	**52.5%**
50-SinPO-BlackJ-Cr										
grid 1	2.7	1.1	21.0	7.0	2.5	1.0	6.3	2.3	0	0
grid 2	3.1	1.2	20.0	7.0	2.9	1.1	6.7	2.4	0	0
grid 3	2.7	2.7	32.0	32.0	2.2	2.2	5.4	5.4	0	0
grid 4	5.9	5.9	40.0	40.0	5.4	5.4	11.7	11.7	0	0
grid 5	9.0	9.0	57.0	57.0	8.7	8.7	16.9	16.9	21	21
grid 6	6.7	6.7	60.0	60.0	6.3	6.3	12.1	12.1	0	0
grid 7	14.1	14.1	98.0	98.0	13.4	13.4	27.8	27.8	107	107
grid 8	5.5	5.5	42.0	42.0	5.2	5.2	10.6	10.6	0	0
grid 9	3.5	3.5	23.0	23.0	3.2	3.2	6.5	6.5	0	0
					Average of highest 1/2/3/4/6/9 grid cells				50-SinPO-BlackJ-Cr	
					30-Day Moving GeoMean of Daily Max					
					Average		Maximum		Reduction Needed	
					surface	depth-avg	surface	depth-avg	Average	Maximum
				max grid	13.4	13.4	27.8	27.8	Meets Standard	**49.7%**
				avg of 2 girds	11.0	11.0	22.4	22.4		**37.4%**
				avg of 3 girds	9.4	9.4	19.0	19.0		**26.1%**
				avg of 4 girds	8.4	8.4	17.1	17.1		**18.3%**
				avg of 6 girds	7.0	7.0	14.3	14.3		**1.9%**
				avg of 9 girds	5.5	5.2	11.6	10.6		**OK**

Table 5-2 (continued).

Group	Daily Max				30-Day Moving GeoMean of Daily Max				Number of Days GeoMean Exceeded Standard	
	Average		Maximum		Average		Maximum			
	surface	depth-avg	surface	depth-avg	surface	depth-avg	surface	depth-avg	surface	depth-avg
49-Sin-SN03-PTOW										
grid 1	6.7	4.6	25.0	18.0	6.5	4.4	12.6	9.2	0	0
grid 2	15.8	10.0	78.0	47.0	15.3	9.7	25.5	16.8	171	34
grid 3	6.8	4.9	24.0	19.0	6.3	4.6	8.9	6.6	0	0
grid 4	3.2	1.9	13.0	9.0	3.1	1.8	5.0	3.0	0	0
grid 5	4.5	2.6	20.0	11.0	4.3	2.6	7.5	4.4	0	0
grid 6	3.4	2.1	17.0	10.0	3.3	2.0	5.3	3.3	0	0
grid 7	2.2	0.8	10.0	4.0	2.1	0.8	3.7	1.6	0	0
grid 8	2.8	1.2	15.0	6.0	2.7	1.1	5.0	2.0	0	0
grid 9	2.5	1.1	11.0	4.0	2.5	1.1	4.6	1.8	0	0

	Average of highest 1/2/3/4/6/9 grid cells				49-Sin-SN03-PTOW			
	30-Day Moving GeoMean of Daily Max				surface		depth-avg	
	Average		Maximum		Reduction Needed			
	surface	depth-avg	surface	depth-avg	Average	Maximum	Average	Maximum
max grid	15.3	9.7	25.5	16.8	8.6%	45.1%	Meets Standard	16.6%
avg of 2 girds	10.9	7.2	19.1	11.7	Meets Standard	26.6%		Meets Standard
avg of 3 girds	9.4	6.3	15.4	10.9		9.0%		
avg of 4 girds	8.1	5.3	13.4	9.2		Meets Standard		
avg of 6 girds	6.5	4.2	10.5	7.1				
avg of 9 girds	5.1	3.1	8.4	5.3				

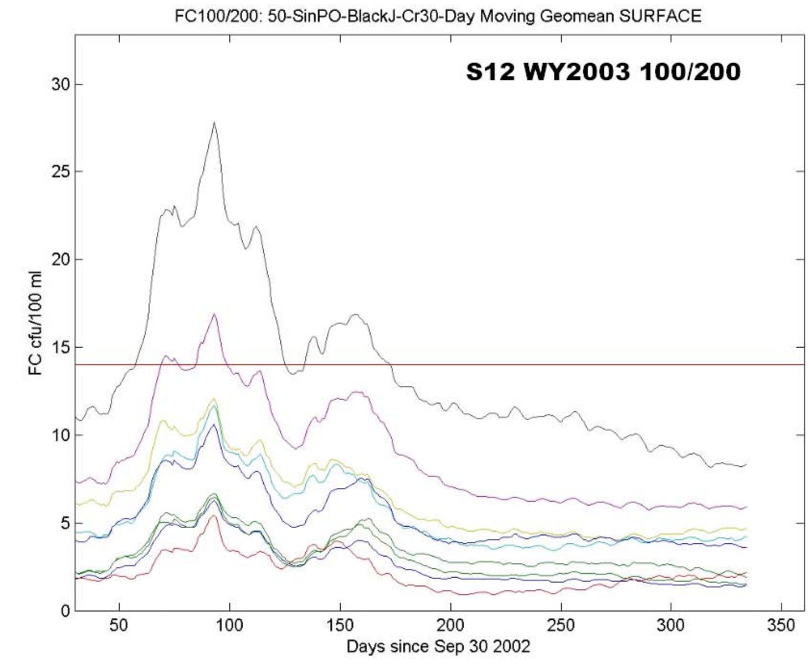


Figure 5-5. The simulated 30-day moving geomean for the surface grid cells of Canary Node 50-SinPO-BlackJ-Cr from simulation scenario S12 WY2003 100/200. See Figure 5-3 for Canary Node location.

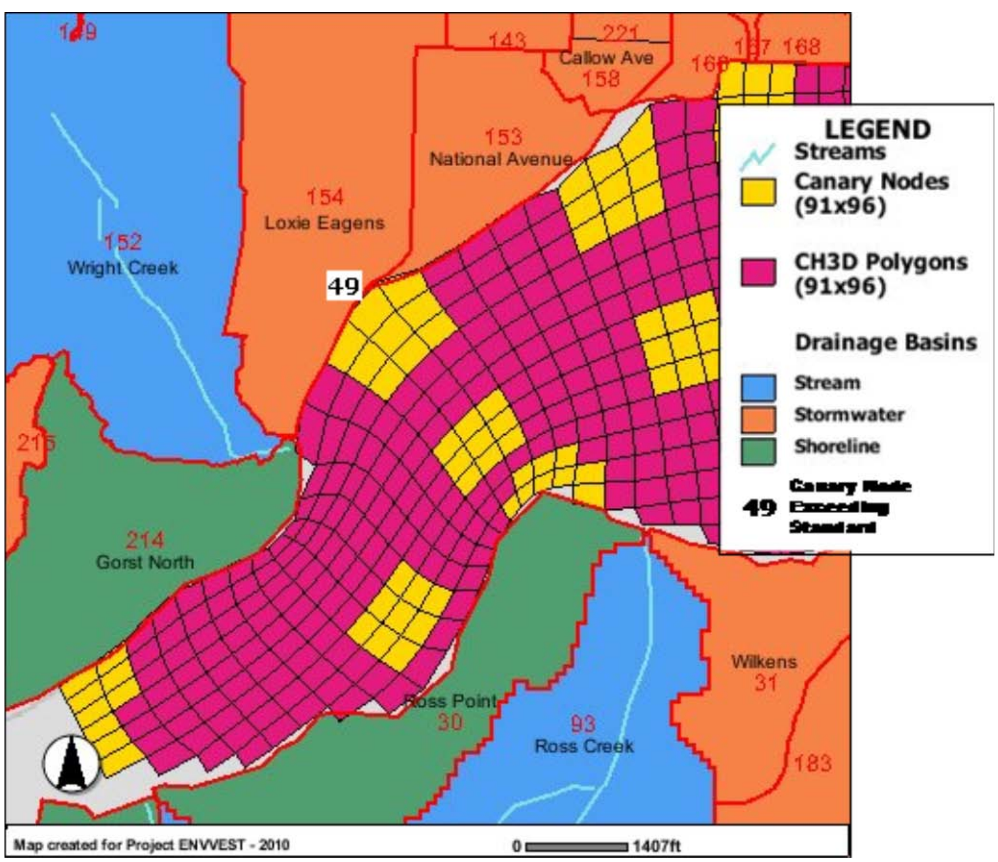


Figure 5-6. Location of Canary Node 49-Sin-SNO3-PTOW in Sinclair Inlet.

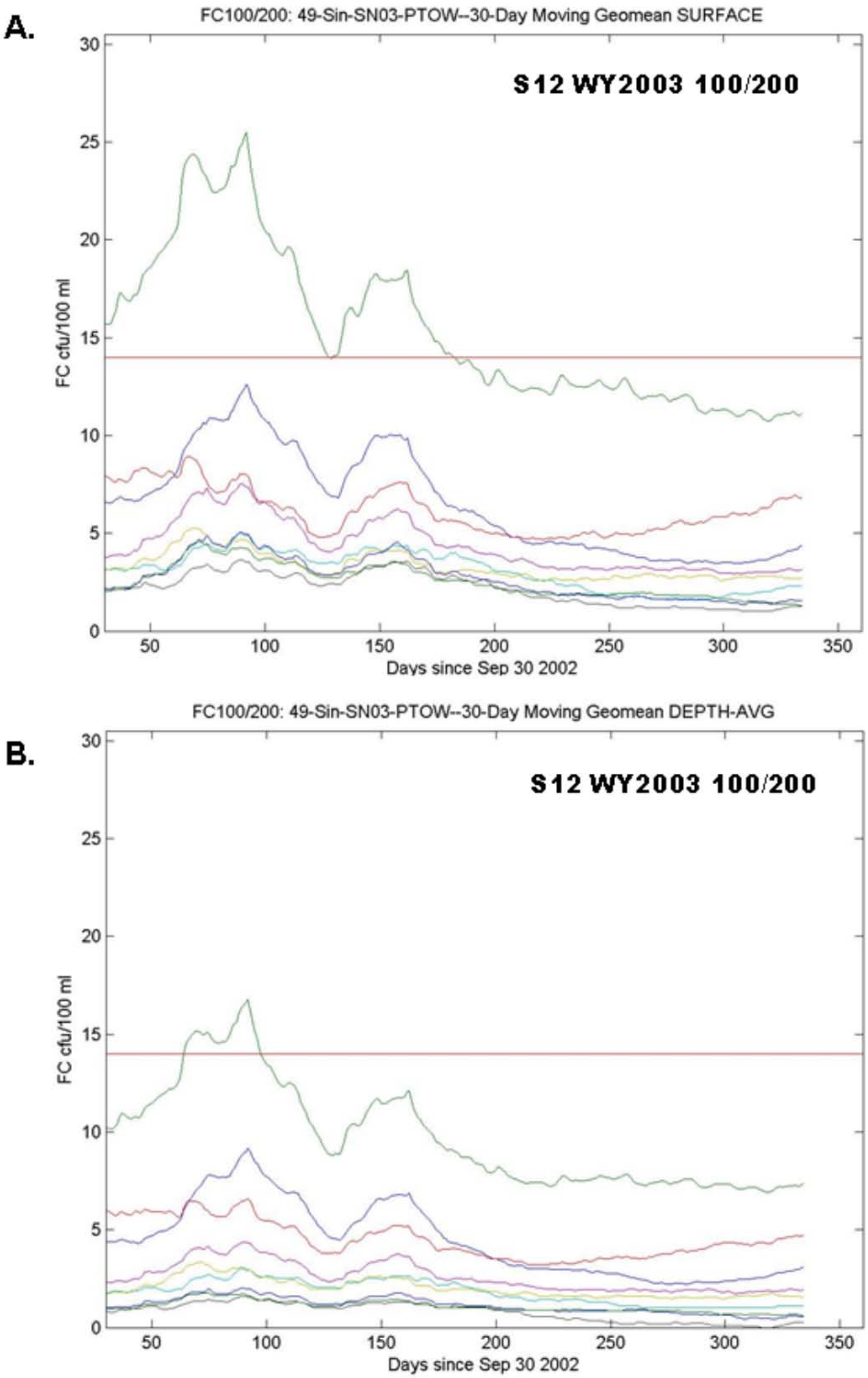


Figure 5-7. The simulated 30-day moving geomean for the surface grid cells (A) and depth-averaged grid cells (B) for Canary Node 49-Sin-SN03-PTOW from simulation scenario S12 WY2003 100/200.

5.3 WY2003 200/400

The simulation results for S13 (TMDL 200/400) using the 91 x 96 grid are summarized below; supplemental information including all the S13 simulation results are available on the distribution CD or via the internet (Table 1-1). For simulation S13, all streams and stormwater outfalls were set to 200 cfu/100 ml, and all WWTPs[14] were set to 400 cfu/100 ml. The daily maximum was used to calculate a 30-day moving 90th percentile to compare to Part II of the standard (43 cfu/100 ml) using the equations described above.

The results for the TMDL 200/400 simulation showed that Part II of the standard (43 cfu/100 ml) was exceeded at five of the canary nodes (Table 5-3). Clear and Strawberry Creeks (Figure 5-8) had two grids that exceeded the standard, one for 56 days and the other for 48 days. A reduction of 9.9 to 30.6% was needed to meet the standard in the nearshore below Clear and Stawberry Creeks. For Gorst Creek (Figure 5-9), all the grids exceeded Part II of the standard for 30 to 334 days, and a reduction of 14 to 78.5% would be required to meet water quality standards (Table 5-3). At Barker Creek, one grid exceeded the standard for 11 days, and an 8.4% reduction would be needed to meet the standard (Figure 5-10). The canary nodes located near Bremerton's Sinclair WWTP (SN03, Figure 5-11) outfall exceeded Part II of the standard for 121 and 6 days in one surface and depth-averaged grid, respectively. The canary nodes at the mouth of Blackjack Creek (Figure 5-12) exceeded the standard at two grids, one for 100 days and the other for 15 days (Table 5-3). Based on these results, the simulated FC loads would need to be reduced by 0.2 to 37.3% to meet the standard at SN03, and 14.9 to 47.4% to meet the standard at Blackjack Creek (Table 5-3). All the other canary nodes met Part II of the standard for the WY2003 simulation using the 200/400 loading conditions.

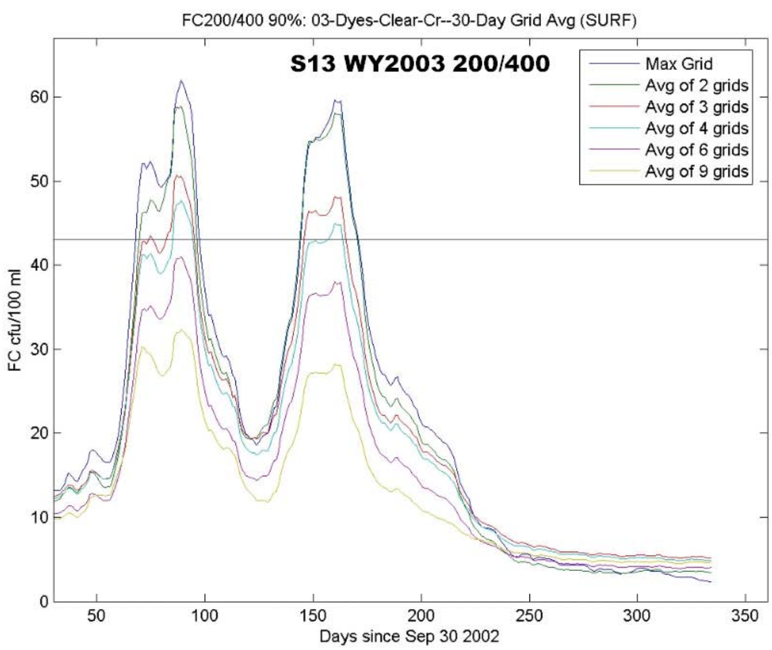


Figure 5-8. The simulated 30-day moving 90th percentile for the surface grid cells of Canary Node 03-Dyes-Clear-Cr from simulation scenario S13 WY2003 200/400. See Figure 5-1 for Canary Node location.

[14] No discharges were programmed for the Bremerton Eastside Treatment Facility because the facility is designed to come online in response to storm events to treat combined sewer overflows (City of Bremerton, 2005; 2007).

Table 5-3. Summary of results for canary nodes that exceeded Part II of the standard for the TMDL 200/400 simulation (S13).

PART II OF STANDARD 90th Percentile > 43 cfu/100 ml (200/400 Simulation)										
Group	Daily Max				30-Day Moving 90th Percentile of Daily Max				Number of Days 90th Percentile Exceeded Standard	
	Average		Maximum		Average		Maximum			
	surface	depth-avg	surface	depth-avg	surface	depth-avg	surface	depth-avg	surface	depth-avg
01-Dyes-Barker-Cr-										
grid 1	3.7	3.7	44.0	44.0	7.6	7.6	19.9	19.9	0	0
grid 2	5.1	5.1	48.0	48.0	10.4	10.4	28.7	28.7	0	0
grid 3	7.9	7.9	54.0	54.0	19.2	19.2	46.9	46.9	11	11
grid 4	1.1	0.3	10.0	4.0	2.5	0.9	6.0	2.3	0	0
grid 5	0.9	0.6	8.0	5.0	2.5	1.4	6.3	3.4	0	0
grid 6	1.0	0.6	7.0	4.0	2.8	1.6	7.3	4.2	0	0
grid 7	0.4	0.1	5.0	2.0	1.0	0.4	3.0	1.1	0	0
grid 8	0.3	0.2	5.0	4.0	1.0	0.7	3.1	2.1	0	0
grid 9	0.4	0.3	6.0	4.0	1.0	0.8	3.4	2.6	0	0
					Average of highest 1/2/3/4/6/9 grid cells				01-Dyes-Barker-Cr-	
					30-Day Moving 90th% of Daily Max					
					Average		Maximum		Reduction Needed	
					surface	depth-avg	surface	depth-avg	Average	Maximum
			max grid		19.2	19.2	46.9	46.9	Meets Standard	8.4%
			avg of 2 girds		14.8	14.8	37.8	37.8		Meets Standard
			avg of 3 girds		12.4	12.4	31.9	31.9		
			avg of 4 girds		10.0	9.7	25.6	24.9		
			avg of 6 girds		7.5	6.9	19.2	17.5		
			avg of 9 girds		5.3	4.8	13.7	12.3		

Group	Daily Max				30-Day Moving 90th Percentile of Daily Max				Number of Days 90th Percentile Exceeded Standard	
	Average		Maximum		Average		Maximum			
	surface	depth-avg	surface	depth-avg	surface	depth-avg	surface	depth-avg	surface	depth-avg
03-Dyes-Clear-Cr--										
grid 1	4.8	4.8	49.0	49.0	8.5	8.5	23.6	23.6	0	0
grid 2	3.6	3.6	48.0	48.0	9.0	9.0	27.9	27.9	0	0
grid 3	3.4	3.4	47.0	47.0	8.8	8.8	27.7	27.7	0	0
grid 4	6.2	6.2	56.0	56.0	14.5	14.5	39.2	39.2	0	0
grid 5	6.5	6.5	66.0	66.0	20.7	20.7	62.0	62.0	56	56
grid 6	6.2	6.2	64.0	64.0	18.4	18.4	57.5	57.5	48	48
grid 7	10.2	10.2	57.0	57.0	17.2	17.2	36.2	36.2	0	0
grid 8	6.0	6.0	46.0	46.0	8.5	8.5	20.0	20.0	0	0
grid 9	5.7	5.7	43.0	43.0	8.4	8.4	21.9	21.9	0	0
					Average of highest 1/2/3/4/6/9 grid cells				03-Dyes-Clear-Cr--	
					30-Day Moving 90th% of Daily Max					
					Average		Maximum		Reduction Needed	
					surface	depth-avg	surface	depth-avg	Average	Maximum
			max grid		20.7	20.7	62.0	62.0	Meets Standard	30.6%
			avg of 2 girds		19.6	19.6	58.9	58.9		27.0%
			avg of 3 girds		18.8	18.8	50.7	50.7		15.1%
			avg of 4 girds		17.7	17.7	47.7	47.7		9.9%
			avg of 6 girds		14.8	14.8	41.0	41.0		OK
			avg of 9 girds		12.7	12.7	32.3	32.3		

Table 5-3 (continued).

PART II OF STANDARD 90th Percentile > 43 cfu/100 ml (200/400 Simulation)

Group	Daily Max				30-Day Moving 90th Percentile of Daily Max				Number of Days 90th Percentile Exceeded Standard	
	Average		Maximum		Average		Maximum			
	surface	depth-avg	surface	depth-avg	surface	depth-avg	surface	depth-avg	surface	depth-avg
43-Sin-Gorst-Creek										
grid 1	66.2	66.2	197.0	197.0	109.1	109.1	200.0	200.0	334	334
grid 2	35.0	35.0	200.0	200.0	68.1	68.1	146.4	146.4	194	194
grid 3	23.3	23.3	163.0	163.0	46.9	46.9	100.8	100.8	153	153
grid 4	17.7	17.7	98.0	98.0	38.9	38.9	88.2	88.2	135	135
grid 5	12.1	12.1	88.0	88.0	28.9	28.9	79.6	79.6	83	83
grid 6	29.2	29.2	168.0	168.0	63.7	63.7	163.6	163.6	184	184
grid 7	12.4	12.4	150.0	150.0	22.9	22.9	55.6	55.6	30	30
grid 8	17.3	17.3	198.0	198.0	30.6	30.6	80.9	80.9	92	92
grid 9	30.8	30.8	202.0	202.0	43.9	43.9	105.3	105.3	119	119

	Average of highest 1/2/3/4/6/9 grid cells 30-Day Moving 90th% of Daily Max				43-Sin-Gorst-Creek	
	Average		Maximum		Reduction Needed	
	surface	depth-avg	surface	depth-avg	Average	Maximum
max grid	109.1	109.1	200.0	200.0	**60.6%**	**78.5%**
avg of 2 girds	88.6	88.6	173.1	173.1	**51.5%**	**75.2%**
avg of 3 girds	80.3	80.3	169.9	169.9	**46.5%**	**74.7%**
avg of 4 girds	72.0	72.0	152.5	152.5	**40.3%**	**71.8%**
avg of 6 girds	61.8	61.8	133.8	133.8	**30.4%**	**67.9%**
avg of 9 girds	50.3	50.3	113.2	113.2	**14.6%**	**62.0%**

Group	Daily Max				30-Day Moving 90th Percentile of Daily Max				Number of Days 90th Percentile Exceeded Standard	
	Average		Maximum		Average		Maximum			
	surface	depth-avg	surface	depth-avg	surface	depth-avg	surface	depth-avg	surface	depth-avg
49-Sin-SN03-PTOW										
grid 1	13.5	9.2	49.0	35.0	21.2	14.6	40.6	29.2	0	0
grid 2	31.7	20.0	156.0	94.0	41.3	26.4	68.6	45.1	121	6
grid 3	13.6	9.8	47.0	38.0	16.3	12.0	22.5	16.4	0	0
grid 4	6.4	3.7	26.0	17.0	9.2	5.5	14.5	8.8	0	0
grid 5	8.9	5.3	41.0	22.0	12.2	7.1	21.0	11.7	0	0
grid 6	6.8	4.2	33.0	20.0	8.4	5.2	13.4	8.4	0	0
grid 7	4.5	1.8	20.0	8.0	6.9	2.7	11.5	4.4	0	0
grid 8	5.6	2.2	30.0	12.0	8.4	3.3	15.4	5.8	0	0
grid 9	5.0	2.0	22.0	8.0	7.4	3.0	13.0	5.1	0	0

	Average of highest 1/2/3/4/6/9 grid cells 30-Day Moving 90th% of Daily Max				49-Sin-SN03-PTOW	
	Average		Maximum		Reduction Needed	
	surface	depth-avg	surface	depth-avg	Average	Maximum
max grid	41.3	26.4	68.6	45.1	**Meets Standard**	**37.3%**
avg of 2 girds	31.3	20.5	54.6	37.2		**21.2%**
avg of 3 girds	26.3	17.7	43.1	30.2		**0.2%**
avg of 4 girds	22.8	15.0	37.5	25.6		**Meets Standard**
avg of 6 girds	18.1	11.8	29.9	19.7		
avg of 9 girds	14.6	8.9	23.8	14.8		

Table 5-3 (continued).

Group	Daily Max				30-Day Moving 90th Percentile of Daily Max				Number of Days 90th Percentile Exceeded Standard	
	Average		Maximum		Average		Maximum			
	surface	depth-avg	surface	depth-avg	surface	depth-avg	surface	depth-avg	surface	depth-avg
50-SinPO-BlackJ-Cr										
grid 1	5.5	2.0	42.0	15.0	8.5	3.1	20.1	7.1	0	0
grid 2	6.2	2.3	39.0	13.0	9.6	3.5	21.0	7.4	0	0
grid 3	5.5	5.5	64.0	64.0	7.0	7.0	16.2	16.2	0	0
grid 4	11.8	11.8	81.0	81.0	16.6	16.6	35.1	35.1	0	0
grid 5	18.0	18.0	115.0	115.0	26.0	26.0	50.2	50.2	15	15
grid 6	13.4	13.4	119.0	119.0	18.6	18.6	35.1	35.1	0	0
grid 7	28.2	28.2	195.0	195.0	39.8	39.8	81.7	81.7	100	100
grid 8	11.0	11.0	84.0	84.0	14.9	14.9	29.6	29.6	0	0
grid 9	6.9	6.9	46.0	46.0	9.3	9.3	18.3	18.3	0	0
					Average of highest 1/2/3/4/6/9 grid cells 30-Day Moving 90th% of Daily Max				50-SinPO-BlackJ-Cr	
					Average		Maximum		Reduction Needed	
					surface	depth-avg	surface	depth-avg	Average	Maximum
			max grid		39.8	39.8	81.7	81.7	Meets Standard	47.4%
			avg of 2 girds		32.9	32.9	65.9	65.9		34.8%
			avg of 3 girds		28.1	28.1	55.6	55.6		22.7%
			avg of 4 girds		25.2	25.2	50.5	50.5		14.9%
			avg of 6 girds		20.9	20.9	42.1	41.7		OK
			avg of 9 girds		16.7	15.4	34.2	31.2		OK

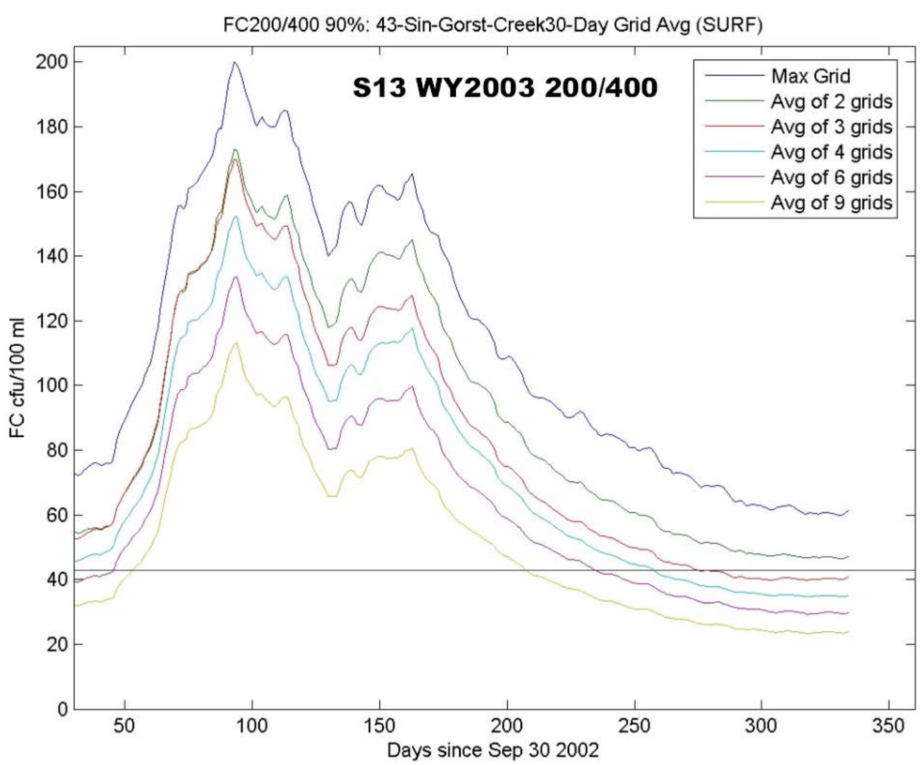


Figure 5-9. The simulated 30-day moving 90th percentile for the surface grid cells of Canary Node 43-Sin_Gorst-Creek from simulation scenario S13 WY2003 200/400. See Figure 5-2 for Canary Node location.

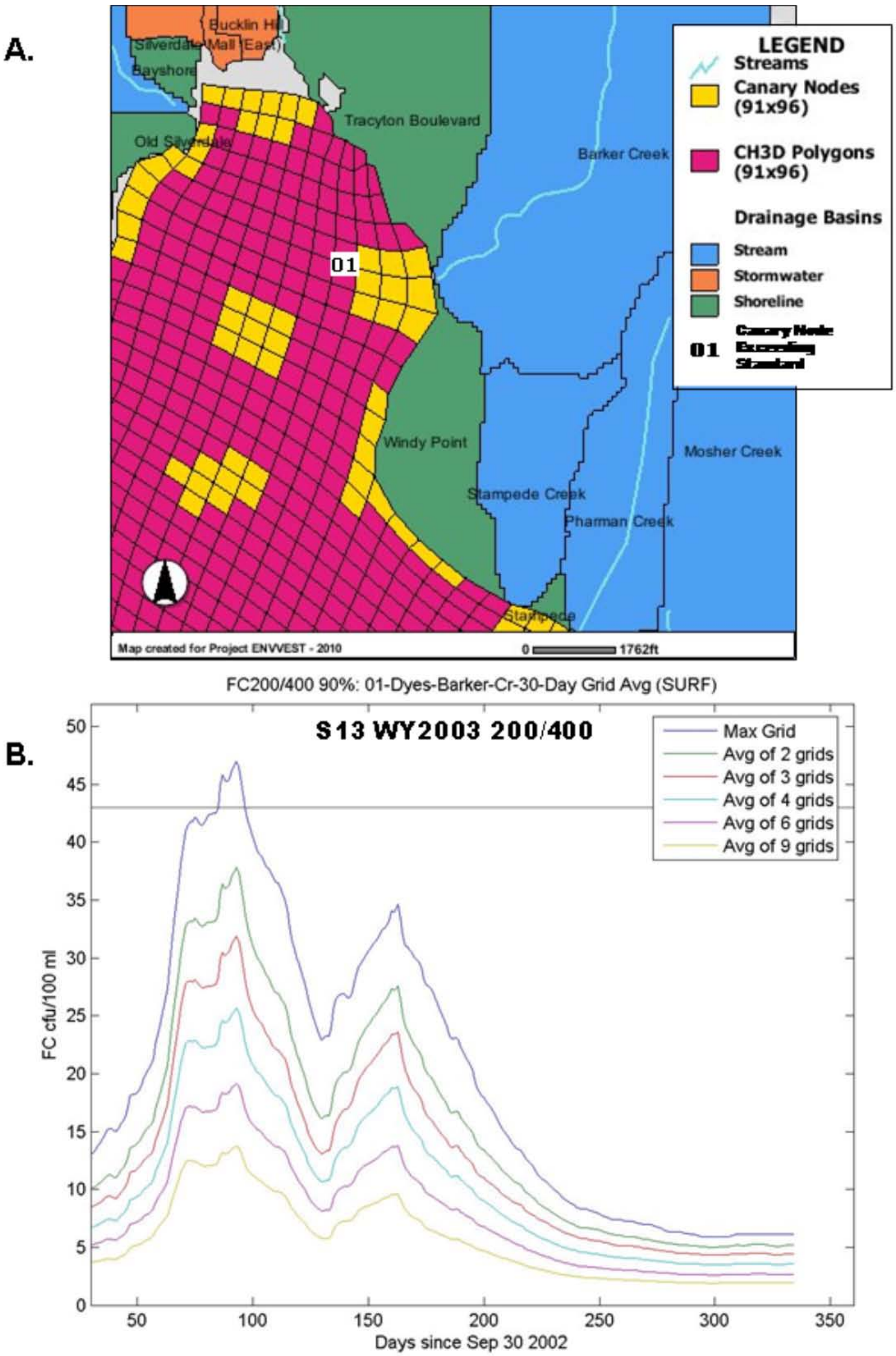


Figure 5-10. Location of Canary Node 01-Dyes-Barker-Cr (A) and simulated 30-day moving 90th percentile for the surface grid cells (B) from simulation scenario S13 WY2003 200/400.

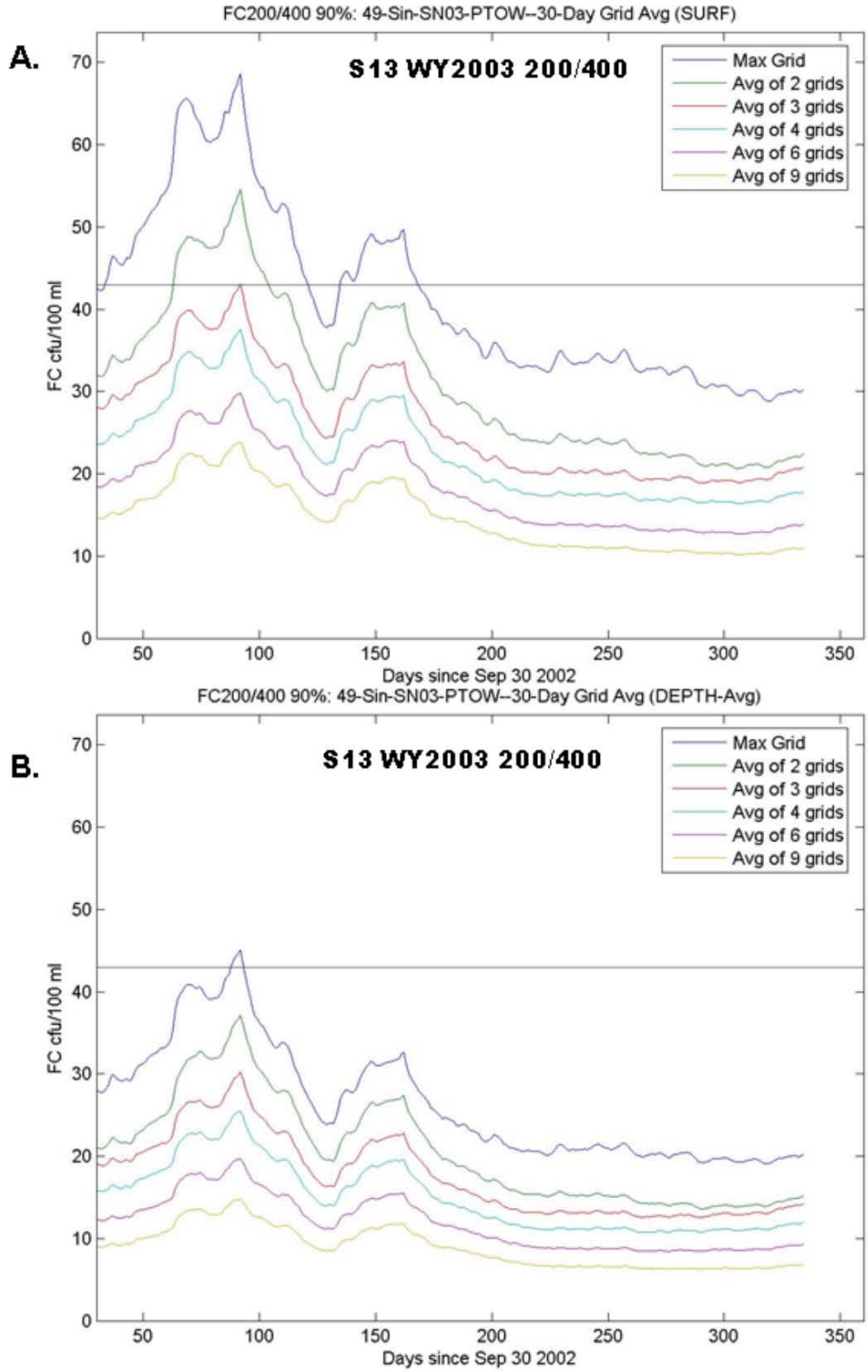


Figure 5-11. Simulated 30 day moving 90th percentile for the surface (A) and depth-averaged (B) grid cells of Canary Node 49-Sin-SN03-PTOW from simulation scenario S12 WY2003 200/400. See Figure 5-6 for Canary Node location.

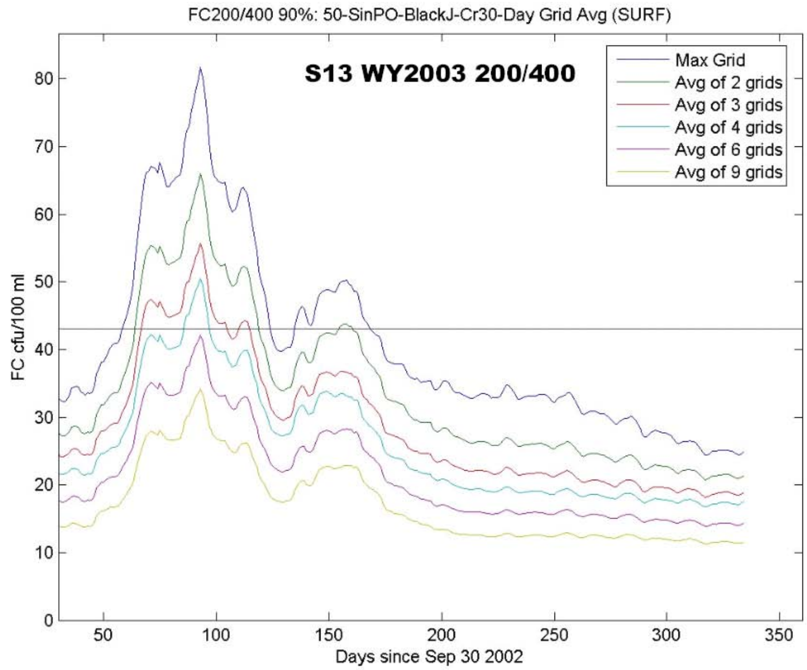


Figure 5-12. The simulated 30-day moving 90th percentile for the surface grid cells of Canary Node 50-SinPO_BlackJ-Cr from simulation scenario S13 WY2003 200/400. See Figure 5-3 for Canary Node location.

5.4 Comparison to Standards of Observed Data

As another line of evidence, we compared the observed data to the water quality standards. The observed data available for WY2003 were grouped according to canary nodes and the number of samples, geomean, and 90th percentile were calculated for each group and compared to Parts I and II of the standard (Table 5-4). Three canary nodes exceeded both Parts I and II (Fort Ward and Lynnwood Cove on Bainbridge Island and Blackjack Creek in Port Orchard). Three other canary nodes exceeded Part II of the standard: Clear/Strawberry Creek, Anderson Cove/Pine Rd, and Olney (Karcher) Creek (Table 5-4). Note that observed data for WY2003 were not available to evaluate water quality standards for the canary nodes located at the SE end of Bainbridge Island (canary node 25), near the shipyard (canary nodes 26-30), along the mid channel of Sinclair Inlet (canary nodes 39-42), and near the head of Sinclair Inlet (canary node 46) (Table 5-4, see Figure 4-5 for canary node locations).

Table 5-4. Summary of the number of samples, geomean, and 90th percentile and comparison to Parts I and II of the standard for each canary node based on observed data from WY2003.

	Observed Data			Water Quality Standard			
				Part 1		Part 2	
Group	n	Geomean	90th %	≥ 14	Reduction Needed	≥ 43	Reduction Needed
01-Dyes-Barker-Cr-	26	2.2	6.6	OK		OK	
02-Dyes-Chico-Cr--	60	4.1	16.6	OK		OK	
03-Dyes-Clear-Cr--	23	13.0	140.3	OK		YES	**69.3%**
04-Dyes-DY24-Straw	18	4.2	23.9	OK		OK	
05-Dyes-DY28-ClamI	16	1.6	3.2	OK		OK	
06-Dyes-DY32-Tracy	11	2.3	9.2	OK		OK	
07-Dyes-ErlandsPt-	13	2.4	6.9	OK		OK	
08-Dyes-M5-RockyPt	5	3.1	6.3	OK		OK	
09-Dyes-M7-MidWind	5	1.8	4.6	OK		OK	
10-Dyes-Windy-Pt--	11	2.7	7.3	OK		OK	
11-Dyes-wShore----	17	2.4	4.7	OK		OK	
12-Ostrich-Bay-M6-	20	1.8	3.4	OK		OK	
13-Ostrich-eShore-	15	2.1	3.8	OK		OK	
14-Ostrich-JackPar	5	2.0	3.9	OK		OK	
15-Ostrich-OBCreek	32	2.9	8.5	OK		OK	
16-OysterBay-all--	46	3.5	14.7	OK		OK	
17-PhinnyBay-sEnd-	27	2.5	7.3	OK		OK	
18-POP-SN17-Waterm	11	2.4	8.2	OK		OK	
19-POP-Dee-Cr-----	11	5.7	38.0	OK		OK	
20-POP-IllaheeSPCr	4	1.8	2.1	OK		OK	
21-POP-M1-MidChann	17	2.3	5.8	OK		OK	
22-POP-PO11-------	26	1.6	3.5	OK		OK	
23-POPASS-PO12----	27	1.8	2.9	OK		OK	
24-POP-SpringBroCr	8	2.8	7.4	OK		OK	
25-POP-sBainbridge							
26-PSNS-P1-ResBasn							
27-PSNS-P2-NavSta-							
28-PSNS-P3-FleetCe							
29-PSNS-P4-CIA-DD-							
30-PSNS-P5-FerryTe							
31-PWN-DY01-mouth-	11	1.7	4.1	OK		OK	
32-PWN-EvergrnPark	6	9.8	16.9	OK		OK	
33-PWN-AnCov-PineR	21	7.2	68.7	OK		YES	**37.5%**
34-RPass-ClamBay--	7	8.6	17.8	OK		OK	
35-RPass-FortWard-	13	21.6	217.0	YES	35.3%	YES	**80.2%**
36-RPass-LynhwoodC	5	72.6	277.7	YES	80.7%	YES	**84.5%**
37-RPass-M2-midChn	16	1.3	2.3	OK		OK	
38-RPas-SN18-Entra	11	1.5	4.3	OK		OK	
39-Sin-M3.1-midChn							
40-Sin-M3.2-midChn							
41-Sin-M3.3-midChn							
42-Sin-M3.4-midChn							

Table 5-4 (continued).

Group	Observed Data			Water Quality Standard			
				Part 1		Part 2	
	n	Geomean	90th %	≥ 14	Reduction Needed	≥ 43	Reduction Needed
43-Sin-Gorst-Creek	17	3.0	10.4	OK		OK	
44-Sinclair-M3-mid	16	2.3	5.9	OK		OK	
45-Sinclair-M4-mid	7	6.8	14.1	OK		OK	
46-Sin-M4.5-head--							
47-Sin-RossPt-SN08	11	2.5	7.6	OK		OK	
48-Sinclair-SaccoC	11	2.7	14.8	OK		OK	
49-Sin-SN03-PTOW--	16	2.4	7.6	OK		OK	
50-SinPO-BlackJ-Cr	6	31.2	72.2	YES	**55.1%**	YES	40.4%
51-SinPO-KarcherCr	16	7.5	50.6	OK		YES	**15.0%**
52-SinPO-SN10-wfro	16	4.9	20.1	OK		OK	
53-Sin-SN11-12mari	27	4.4	20.8	OK		OK	

5.5 Summary of TMDL Simulations

We conducted the TMDL simulations to determine the level of FC that could be discharged from streams, shorelines, stormwater outfalls, and WWTPs and still meet water quality standards in the receiving waters. The TMDL runs simulated WY2003 for the following conditions:

- Actual conditions with streams, shoreline, and stormwater outfalls set to the estimated geomean concentration and WWTP to actual concentrations from the DMRs (Actual);
- Part I of the standard by setting the streams, shorelines, and stormwater outfalls to 100 cfu/100 ml and WWTPs to 200 cfu/100 ml (TMDL 100/200); and
- Part II of the standard by setting the streams, shorelines, and stormwater outfalls to 200 cfu/100 ml and WWTPs to 400 cfu/100 ml (TMDL 200/400).

Additionally, the geomean and 90th percentile calculated for observed data from WY2003 for each canary node were compared to Parts I and II of the standard. The results showed that reductions would be required to meet water quality standards at 9 of the 53 canary nodes (Table 5-5). The areas and the major pour points contributing FC pollution to the areas that required reductions include the mouths of Barker, Clear/Strawberry, Gorst, Blackjack, and Olney (Karcher) Creeks, Anderson Cove, and Pine Rd outfall in the Port Washington Narrows, and the south shore of Bainbridge Island (Table 5-5).

Table 5-5. Summary of canary nodes requiring reductions to meet water quality standards based on observed data and results from simulations of FC loading from actual conditions, TMDL 100/200, and TMDL 200/400.

	% Reduction Needed to Meet Standard			
		SIMULATED		
Canary Node	**OBSERVED**	**Actual**	**TMDL 100/200**	**TMDL 200/400**
01-Dyes-Barker-Cr				8.4%
03-Dyes-Clear-Cr	69.3%	15.2%		9.9% - 30.6%
33-PWN-AnCov-PineR	37.5%			
35-RPass-FortWard	35.3% - 80.2%			
36-RPass-LynnwoodC	80.7% - 84.5%			
43-Sin-Gorst-Cr		24.7%	14.7% - 77.0%	14.6% - 78.5%
49-Sin-SNO3-PTOW			8.6% - 45.1%	0.2% - 37.3%
50-SinPO-BlackJ	40.4% - 55.1%	4.1%	1.9% - 49.7%	14.9% 47.4%
51-SinPO-KarcherC	15.0%			

6. CONCLUSIONS

We conducted an integrated monitoring and modeling project to assess the total loading of bacteria in Sinclair and Dyes Inlets in the Puget Sound, Washington. Streams, stormwater outfalls, treatment plant outfalls, and receiving waters were sampled during the dry season, wet season, and storm events to characterize bacterial loading from a range of representative landscapes present within the watershed (May et al., 2005). The watershed model Hydrologic Simulation Program FORTRAN (HSPF) used landscape-scale characteristics, monitored flow, and measured precipitation data to simulate flow draining into the inlets. Statistical clustering of the monitored watersheds was used to estimate bacterial concentrations in the unmeasured drainage basins. Finally, the Curvilinear Hydrodynamics in Three-Dimensions (CH3D) model simulated vertical and horizontal mixing and the fate of bacteria in the marine environment as a function of salinity, temperature, mixing depth, and sunlight. Implementing the models to simulate bacterial pollution in the inlets stimulated stakeholder involvement and helped focus and optimize data gathering activities, while the empirical data provided the information needed to refine model assumptions, determine boundary conditions, and corroborate model predictions.

We found that the HSPF submodels simulated runoff from streams and stormwater outfalls in the watershed with a high degree of accuarcy. The watershed models simulated watershed-scale hydrology of the Sinclair and Dyes Inlets watershed with GOOD-to-EXCEPTIONAL accuracy for streams and FAIR-to-GOOD accuracy for stormwater basins. Additionally, CH3D simulated the tides and currents with a high degree of accuracy, increasing our confidence that the hydrodynamic tides and currents were well simulated for most of the inlets. The k-cluster regression used to predict FC loading based on upstream land use and cover and runoff from the watershed resulted in GOOD-to-EXCELLENT agreement with observed data for streams. There was also the added benefit of being able to obtain estimates of FC sources, without extrapolation, from the other drainage basins for which no data were available. Although there was more uncertainty with the empirical estimates of FC concentrations in stormwater systems, the stormwater approach was practical, took advantage of the available information, and was able to provide a reasonable estimate of FC concentrations in stormwater systems. The loading estimates for the WWTPs derived from DMRs adequately captured the variation and magnitude of the discharges and provided a good estimate of FC loading from these sources.

We ran the estuarine CH3D-FC model to simulate the tides, circulation conditions, fresh water, and FC inputs occurring during individual storm events (10 days) and over the course of WY2003 (364 days). Based on the comparison to observed data, we had a high degree of confidence that the CH3D-FC could simulate FC fate and transport in the inlet. There was GOOD-to-EXCELLENT agreement between model predictions and observed data for marine waters; however, the model tended to underpredict FC concentrations in certain nearshore areas, including the mouths of Clear and Strawberry Creeks, in Oyster Bay, near the mouth of Dee Creek, along the Port Orchard waterfront, and along the southern shore of Bainbridge Island.

We identified uncertainties and limitations of the modeling study. The model was designed to simulate FC loading as a function of upstream land use and cover determined from the empirical data collected from the watershed. The model indirectly accounts for sources from failed septic systems, leaking sewer infrastructure, and upland waterfowl and wildlife only to the extent that these sources contributed to the empirical data used to develop the FC loading concentration estimates (see Section 2.2). Potential sources of FC not in the model included marinas, recreational and commercial

boating, broken pipes, CSO events, sediment resuspension, regeneration of bacteria spores, nearshore waterfowl, marine mammals, and any other unknown sources.

The sensitivity analysis showed that the most important factors affecting the distribution of FC in the inlets were the FC loading, which was controlled by the loading concentration and freshwater flows, physical mixing, and FC die-off. Wind and small changes to freshwater flows did not appear to have much effect on the FC distribution in the inlets.

The uncertainty analysis of the effect of future build-out on FC loading showed that expanded build-out would likely increase the frequency, magnitude, extent, and duration of FC levels exceeding water quality standards through out the watershed. The futures analysis assumed that the modeling system developed to represent present conditions was also applicable to future build-out and that the relationships between LULC and modeled flow and between LULC and predicted FC concentrations were still valid. The uncertainty associated with the futures analysis lessens the confidence that we can place on the results of the future predictions because the future is unknown. However, it is likely that any actions that effectively eliminate or reduce present problems would also be effective in addressing future problems.

We conducted specific simulations needed to support load and waste load reduction for the TMDL. We defined groups of model grids, or canary nodes that were located in strategic locations to evaluate whether standards were exceeded. The model was run to simulate "actual conditions" for WY2003 to identify areas that exceeded water quality standards. Simulations of WY2003 were also conducted to calculate waste load and load allocations for streams, stormwater outfalls, and waste water treatment plants (WWTPs) for Part I of the standard by setting the streams and stormwater outfalls to 100 cfu/100 ml and WWTPs to 200 cfu/100 ml. Waste loads and load allocations for Part II of the standard were simulated by setting the streams and stormwater outfalls to 200 cfu/100 ml and WWTPs to 400 cfu/100 ml. Additionally, the geomean and 90th percentile calculated for observed data from WY2003 for each canary node were compared to Parts I and II of the standard. The results showed that reductions would be required to meet water quality standards at the mouths of Barker, Clear/Strawberry, Gorst, Blackjack, and Olney Creeks, Anderson Cove/Pine Rd in the Port Washington Narrows, and the south shore of Bainbridge Island.

Overall, the model performed very well, recreating a wide range of dynamic loading within the inlets, from large-scale storm events with high flow conditions to dry, low-flow conditions during the summer months. Although data were limited for many of the stations in Sinclair Inlet, especially near the Shipyard and other areas likely to receive stormwater runoff from the Cities of Bremerton and Port Orchard, the model reproduced FC loading episodes with a high degree of accuracy. We had very high confidence that the model could simulate watershed-scale FC loading, fate, and transport in the inlets, and the stakeholder group deemed that the predictions were acceptable within the identified limitations. The integrated watershed monitoring and modeling approach to water quality management is assisting the development of management plans worthy of stakeholder acceptance, helping to achieve reductions in FC loading, and resulting in improvements to the environmental quality of the inlets.

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14. ABSTRACT

The setup, calibration, verification, and evaluation of an integrated watershed and receiving water model developed to model fecal coliform (FC) bacteria loading, fate, and transport in Sinclair and Dyes Inlets, Puget Sound, WA, is reported. The integrated model consisted of a watershed model, an empirical FC loading model, and an estuarine fate and transport model that was used to simulate FC bacteria loading from streams, stormwater outfalls, shoreline runoff locations, and treatment plant discharges to determine the impact to water quality of the inlets. Scenarios of bacteria loading from all known sources were simulated to support a total maximum daily load (TMDL) study of bacterial pollution for the inlets. Overall, the integrated watershed-receiving water model performed very well, reproducing watershed-scale FC loading, fate, and transport in the inlets with a high degree of accuracy; the stakeholder group deemed that the predictions were acceptable within the limitations identified.

15. SUBJECT TERMS

Dyes Inlet, WA	Evapotranspiration	Curvilinear Hydrodynamics in Three Dimensions (CH3D)
Fate and Transport	Fecal Coliform	Hydrologic Simulation Program Fortran (HSPF)
Sinclair Inlet, WA	Total Maximum Daily Load (TMDL)	

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